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and Energy Requirements in Military and Civilian Women

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FOREWORD

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5. INTRODUCTION

A. Subject, Hypothesis and Technical Objectives of the Research

The level of fatness associated with optimal physical fitness in women is less than the level of fatness associated with optimal fetal growth and survival. Women with low pre-pregnancy energy stores are at greater risk for fetal loss, premature delivery and intrauterine growth retardation. However, a low pre-pregnancy body mass index (BMI) can be compensated for by a greater pregnancy weight gain. In this study the effect of physical activity level on changes in physical fitness, weight, FFM, fat mass, energy expenditure will be evaluated through a complete reproductive cycle in sixty-eight women stratified by pre-pregnancy BMI. Measurements will be done prior to pregnancy to establish pre-pregnancy nutritional status and physical fitness. During pregnancy measurements will be made at 8 wk (first trimester), 22 wk (second trimester), and 36 wk (third trimester). Postpartum measurements will be made at 2 wk to establish postpartum baseline body composition; at 6 wk when military and many civilian women return to work; and at 24 wk when military women must meet weight and physical fitness standards. We will investigate if military policies requiring women to return to weight and physical fitness standards by 6 mo postpartum are physiologically reasonable. The appropriateness of military body weight retention standards and the accuracy of the military equations used to predict body fat will be assessed in postpartum women.

Hypothesis

Moderate levels of *physical activity* will maintain *physical fitness* and limit *excess fat deposition* during pregnancy without jeopardizing fetal growth if dietary intake is not restricted, and facilitate *fat mobilization* and conserve *fat-free mass* during postpartum weight loss.

Technical Objectives

1. *The effect of physical activity level on pregnancy-induced and postpartum changes in weight, FFM and fat mass will be compared in military and civilian women with low to high pre-pregnancy BMI.* Changes in FFM and fat mass will be computed from measurements of body volume, total body water, potassium, nitrogen and bone mineral through a complete reproductive cycle (pre-pregnancy-6 mo postpartum).
2. *The effect of physical activity level on pregnancy-induced and postpartum changes in physical fitness will be compared in military and civilian women.* Submaximal and maximal aerobic capacity will be measured through a complete reproductive cycle. The impact of body composition (specifically FFM, muscle mass and body fat), and iron status on physical performance will be assessed.
3. *The effect of physical activity level on the energy requirements of physically-active military and civilian adult women will be determined prior to pregnancy, during pregnancy*

and postpartum. Energy requirements will be estimated from rates of energy expenditure and energy deposition/mobilization.

B. Background of Previous Work

Military weight and body fat standards

The rationale for weight and body fat standards for accession and retention in the military as stated in Army regulation 600-9 (1) is "to insure that all personnel are able to meet the physical demands of their duties under combat conditions and present a trim military appearance at all times". Although similar, weight and body fat standards differ somewhat among the military services. If an individual exceeds the acceptable weight for height standard, body fat is assessed using anthropometric measures. The Army uses height, weight, and circumferences of neck, forearm, wrist, and hips in women to calculate body fat (2). The Navy uses height, weight and circumferences of neck, waist and hips in women (3). The Marines use height, weight, flexed biceps, forearm, neck, waist and thigh circumferences for women (4). The Air Force uses height, weight and forearm circumference (this equation is no longer used) (5).

The weight and body fat standards for accession and retention differ for men and women. Between 1960 and 1983 the maximum weight limits for women were lowered by 15-20 lbs (AR 40-501)(6). The tables for women are considerably more restrictive relative to the national population. The military standard levels for body fatness are lower in men than women, acknowledging the fact that women biologically have higher body fat.

Table 1. Body fat standards for women as a percent of body weight (7)				
Age	<u>17-20y</u>	<u>21-27y</u>	<u>28-39y</u>	<u>>40y</u>
Army	30%	32%	34%	36%
Navy	-----36%-----			
Air Force	-----28%-----34%-----			

However, accession and retention weight criteria are stricter for women than men. For enrollment into the Army men may be 37% above the desirable weight based on the 1959 Metropolitan Life Insurance Tables, while women can be only 6% above. For retention in the Army men can be 14% above desirable weight, and women only 5% above. Consequently, 29% of women Army recruits are rejected in contrast to 3% of male recruits (8). Military weight standards for women are set at an upper BMI limit of 24. Therefore, military women enter pregnancy with a low to normal BMI.

Performance standards

For retention in the military, personnel are evaluated regularly not only for weight compliance, but also for aerobic fitness (7). Physical fitness tests for women consist of a 1.5-

2-mile run, push-ups and sit-ups or curl-ups. Although the tasks of military women are increasingly diverse, the military contends that all individuals need to maintain a certain level of physical fitness to preserve the combat readiness of the services. If an individual fails to meet the body fat or physical fitness standards, he/she is assigned a program of diet and exercise. Individuals who do not lose sufficient weight or body fat are discharged from the military.

Pregnancy-induced changes in body weight

In the Institute of Medicine (9) appointed a Subcommittee to review the effect of gestational weight gain on maternal and child health and to make recommendations for optimal weight gain during pregnancy. Gestational weight gains associated with optimal infant outcome were found to be a function of maternal pre-pregnancy BMI. Several epidemiologic studies demonstrated that the effect of a given weight gain is greatest in thin women and least in overweight women. Pre-pregnancy BMI is also a determinant of fetal growth above and beyond its effect on gestational weight gain. Women with low pre-pregnancy BMIs tend to have smaller infants than those of their heavier counterparts. Low gestational weight gain is associated with a higher risk of intrauterine growth retardation and subsequent poor somatic and neurobehavioral development. Increased perinatal mortality among infants born to women with low weight gain especially those with low pre-pregnancy weight for height was seen in the Collaborative Perinatal Project (10) and the 1980 National Fetal Mortality Survey (11).

The Subcommittee concluded that desirable gestational weight gains should be based on pre-pregnancy BMI and should include the mean weight gain for women delivering full-term infants with birth weights in the optimal range of 3 to 4 kg (9).

Table 2. Recommended ranges of gestational weight gain by pre-pregnancy BMI (9)

<u>Weight for height category</u>	<u>Recommended total gain (kg)</u>
Low (BMI<19.8)	12.5-18.0
Normal (BMI=19.8-26.0)	11.5-16.0
High (BMI>26.0-29.0)	7.0-11.5

Although gestational weight gain is correlated with birth weight, which component(s) of gestational weight gain is(are) critical for optimal fetal growth is unknown. Fetal growth may be influenced more by specific changes in fat-free mass (FFM), fat or water than by total gestational weight gain. In a study of 56 Swedish women total weight gain (14.8 kg), but not fat mass accretion (4-5 kg), was positively correlated with birth weight (12). However, their estimates of fat mass based on skinfolds were relatively imprecise. In another study of 115 Scottish women the lack of correlation between maternal fat accretion, estimated from weight retention 2-3 wk postpartum, and birth weight was confirmed (13). These results should be interpreted cautiously, since fat accretion was not measured directly and only women with normal pre-pregnancy BMI (22.5) were studied. In women with low pre-pregnancy BMI fat

accretion may be more critical to fetal growth. There may be a threshold for maternal fat gain below which fetal growth is compromised. Further studies on the composition of weight gain in women stratified by BMI and its impact on pregnancy outcome are needed.

Pregnancy-induced changes in body composition

The amount of FFM and fat accreted at any given gestational weight gain is poorly defined. Theoretical estimations of protein and fat deposition in the maternal (uterus, breasts, blood, adipose tissue, extracellular fluid) and fetal (fetus, placenta, amniotic fluid) compartments have been calculated for a 12.5 kg weight gain (14). Total body water increases continuously through pregnancy, primarily in extracellular fluids; therefore, the hydration of FFM increases substantially through pregnancy (15). Protein accretion rates estimated by recent nitrogen balance studies agree with Hytten's theoretical values (16). Therefore, it seems unlikely that protein is stored in excess of the amounts accounted for by the fetus and maternal reproductive tissues. The suggestion that protein is stored in muscle early in pregnancy, based on urinary 3-methylhistidine excretion data (17), has been refuted by others who attributed the higher urinary excretion of 3-methylhistidine to decreased renal tubular reabsorption and higher skeletal muscle turnover (16). Our measurements of total body nitrogen and potassium retention in pregnancy will resolve the amount and partitioning of protein deposited.

During pregnancy fat is deposited primarily in the subcutaneous adipose of the lower and upper trunk, and thighs (18-20), however, the amount of fat deposited is uncertain. Because of the increased hydration of FFM during pregnancy, standard techniques used to estimate fat deposition are invalid during pregnancy. Corrections were not applied in earlier dilution studies (15,21), but were in a later study (22), in which the mean fat gain was 2.77 ± 3.23 kg. Based on underwater weighing corrected for changes in the density of FFM, fat mass accretion was 2.7 ± 2.2 kg (23). Based on combined measurements of TBW and TBK, mean fat gains were 1.87 ± 2.23 kg (24) and 5.8 ± 4.0 kg (25). Recent values of fat gain differ from Hytten's original estimate of 3.3 kg fat. Technical errors undoubtedly contribute to the high variability in fat gain, but gestational weight gain, which is positively correlated with fat gain, is also variable in healthy women (26). Because of wide variation, changes in body composition can only be estimated from serial measurements, preferably with pre-pregnancy baseline values.

Postpartum weight and body fat loss

Postpartum weight loss is influenced by total gestational weight gain, age, parity, pre-pregnancy BMI, and feeding mode (27). The 1988 National Maternal and Infant Survey indicated a strong positive association between gestational weight gain and postpartum weight retention 10 to 18 months postpartum (28). Excessive weight retention was more common in black women in every weight gain category. Greater weight losses were observed in women with lower pre-pregnancy weights (20). Lactation facilitates weight loss in most women. Lactating women averaged 0.7 kg/mo weight loss during the first 4-6 mo postpartum (29,30). This weight loss was compatible with successful lactation and was

associated with a decrease in body fat from 28.0 to 26.3%. Acceleration of weight loss may compromise lactation performance. Short-term energy restriction (1591 kcal/d for 1 wk resulting in a weight loss of 1.18 kg/wk) was associated with a fall in subsequent milk output and infant weight gain (31).

Accelerated weight loss may result in an undesirable loss of muscle mass in postpartum women (32). Whenever body weight is reduced, both FFM and fat mass contribute to the weight loss. For any given change in weight, the ratio $\Delta\text{FFM}/\Delta\text{WT}$ is inversely related to initial body fat. However, exercise-training has been shown to enhance FFM preservation during diet restriction. Moderate exercise training reduced the amount of body weight lost as FFM compared to dietary restriction alone (33). Exercise training also can induce a greater energy deficit and mobilization of fat. We therefore hypothesize that dietary restriction combined with moderate levels of physical activity may preserve FFM in postpartum women.

When pregnant women perform nonweight-bearing exercise such as stationary cycling, oxygen consumption (VO_2 ($\text{l} \cdot \text{min}^{-1}$)) is either unchanged or only slightly increased at any given submaximal work rate compared to nonpregnant women (34). During submaximal weight-bearing exercise (eg. walking, running, treadmill exercise) maternal VO_2 ($\text{l} \cdot \text{min}^{-1}$) is significantly increased approximately in proportion to maternal weight gain. VO_2 expressed in $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ is similar to or slightly reduced during pregnancy compared to nonpregnant state at the same speed and grade of walking. Limited data indicate that maximal VO_2 ($\text{l} \cdot \text{min}^{-1}$) during cycle ergometry and treadmill exercise is not altered by pregnancy compared to the postpartum period (35,36). However, in the only study in which aerobic capacity was assessed prior to pregnancy, $\text{VO}_{2\text{max}}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) during cycle ergometry was higher pre-pregnancy compared to 4 to 8 wk postpartum (37). The decrement in $\text{VO}_{2\text{max}}$ was attributed to increased body weight and decreased physical activity through pregnancy and the postpartum period. Whether this deconditioning effect is an inevitable consequence of pregnancy or whether moderate exercise throughout pregnancy can ameliorate the decline in aerobic capacity is uncertain. The effect of pregnancy-induced changes in body composition on physical fitness has not been evaluated through a reproductive cycle.

Moderate exercise under the ACOG Guidelines (38) poses minimal risk to the mother and her fetus. Such exercise programs may maintain aerobic fitness and control gestational weight gain (34). Strenuous exercise, on the other hand, may result in inadequate weight gain and give rise to smaller (300-500 g less) infants.

Effect of iron status on work capacity and performance

Maximal aerobic capacity is linearly related to hemoglobin concentration in humans (39). In iron deficiency without anemia skeletal muscle function is impaired by a decrease in mitochondrial iron-dependent enzymes of the electron transport chain and cytochromes. Iron deficiency induces a greater dependence on anaerobic glucose utilization, with lactic acidemia as a consequence. These defects reduce endurance and submaximal work performance. This is of practical importance since most human work is performed at submaximal levels (40% of $\text{VO}_{2\text{max}}$). In iron-deficient women without overt anemia total O_2 uptake and total energy expenditure were decreased, and post-exercise lactate concentration

was increased in response to a progressive, graded aerobic capacity test on a cycle ergometer (40). Peak oxygen consumption was not impaired.

Postpartum women are "at risk" for iron deficiency or anemia. Iron losses during pregnancy include loss to the fetus and placenta, blood loss at delivery, and basal losses totalling approx. 840 mg (9). Blood loss during a cesarean delivery is almost twice that of a vaginal delivery. While we do not expect to find overt anemia in pregnant military women under medical surveillance, marginal iron deficiency may be present.

Pregnancy-induced changes in energy requirements

The energy requirement of pregnancy is a topic of considerable uncertainty as reflected in the lack of consensus in international recommendations: +1.20 MJ/d for all trimesters (41); +1.25 MJ/d for the last 2 trimesters (42); +0.80 MJ/d for the third trimester (43).

The energy requirement of pregnancy entails the energy deposited in maternal and fetal tissues and their associated increase in energy expenditure. Basal metabolic rate (BMR) steadily rises through pregnancy, due primarily to the products of conception and to a lesser extent to increased maternal cardiac and respiratory work. By late pregnancy VO_2 is 16-32% above nonpregnant values. Serial measurements of BMR through pregnancy indicate considerable interindividual variation in metabolic response (22,25,44,45), which was correlated to pre-pregnancy fatness, weight gain and fat gain (22). BMR actually declined in the first trimester in some women, suggesting increased metabolic efficiency. The lean women tended to be energy-sparing and the fatter women energy-profligate.

Total energy expenditure (TEE) using room calorimetry (46,47) and the doubly-labeled water method (22,48) has been measured longitudinally in only a few pregnant women. Near term TEE increased 1.5-2 MJ/d. Although changes in BMR accounted for most the increment in TEE, the level of physical activity contributed significantly to the variability in TEE.

The energy requirement of pregnancy will depend on the woman's gestational weight gain and the level of physical activity maintained throughout pregnancy. If a moderate level of physical activity and therefore physical fitness are maintained, it is of paramount importance that dietary intake is sufficient to meet maternal and fetal needs. In women with low pre-pregnancy BMI, if dietary intake is not sufficient to replenish maternal stores, fetal growth will be suboptimal. However, recommendations for dietary intake cannot be made, since the energy requirements of physically active pregnant women with low to normal pre-pregnancy BMI have not been quantified.

Nutritional implications for military women during reproduction

The nutritional problems of military women are similar to physically active civilian women participating in recreational sports. Inadequate intakes of iron and calcium place these weight-conscious women at risk for anemia and osteoporosis (49). Friedl (50) reported that 36.6% of West Point cadets were at risk of developing iron deficiency. Inadequate iron nutriture may impact physical performance through its effect on O_2 transport and oxidative metabolism (39). The nutritional status of military women may be further jeopardized by the need to meet military body weight and fat standards.

Because pregnant military women are required to meet weight and physical fitness standards by 6 mo postpartum, they may restrain food intake and possibly jeopardize fetal growth. Postpartum military women may seriously restrict food intake to accelerate weight loss resulting in loss of fat and FFM, and possibly compromising milk production, if breastfeeding. Military women enter pregnancy with low to normal BMIs, since the military retention weight standards are equivalent to a BMI of 24. We calculated desirable gestational weight gains for optimal infant outcome and postpartum weight loss for women with low and normal pre-pregnancy BMIs (Table 3) based on the IOM recommendations for weight gain; an immediate weight loss associated with the baby, placenta and amniotic fluid of 4.85 kg (14); diuresis resulting in an additional 3.0 kg loss by da 15 postpartum; further weight loss at an average rate of 0.7 kg/mo.

Table 3. Expected gestational weight gain and postpartum weight retention in military women

	<u>Low BMI</u>	<u>Normal BMI</u>
Weight gain (kg)	12.5-18.0	11.5-16.0
Weight retention day 1 postpartum (kg)	7.6-13.1	6.6-11.2
Weight retention day 15 postpartum (kg)	4.6-10.1	3.6-8.2
Weight retention day 42 postpartum (kg)	3.6-9.1	2.7-7.2
Weight retention day 180 postpartum (kg)	0.4-5.9	0.6-4.0

If military women gain at the recommended levels and lose at a reasonable rate postpartum, they will return to active duty at da 42 postpartum with significant excess weight. At 6 mo when military women are expected to meet weight standards, many women will be 0.5-6.0 kg above their pre-pregnancy weight. In order to achieve the weight standards by 6 mo, military women must restrict dietary intake to accelerate weight loss.

The level of physical activity maintained by pregnant military women is uncertain. Although military "pregnancy profiles" exempt women from jobs requiring heavy physical work and eliminates physical fitness testing, these physically-fit women may voluntarily continue to exercise. Or they may become relatively inactive and physical fitness may decline due to deconditioning. Upon returning to work at 6 wk postpartum, military women are expected to perform at their pre-pregnancy work capacity. Whether pre-pregnancy physical fitness has been regained by 6 wk postpartum is uncertain. In only one study was aerobic capacity assessed prior to pregnancy and 4-8 wk postpartum; a decline in aerobic capacity was observed postpartum and attributed to weight gain and decreased physical activity during pregnancy (37). Whether this detraining effect is inevitable during pregnancy or whether exercising throughout pregnancy ameliorates the decline is unknown.

Application of the body fat equations to postpartum women is questionable. Although the prediction equations for body fat have been cross-validated for men and women, they have not been evaluated for postpartum women (3). The Army and Navy equations may overestimate total body fat since these equations use hip circumference, a site of predominate

fat deposition in pregnant women. The Air Force equation may underestimate total body fat since it uses forearm circumference which changes little during pregnancy.

Information relevant to the Military Recommended Dietary Allowances (51) for energy intakes of active duty and reserve military women will be provided by this study. Energy requirements of physically active women will be defined prior to, during and after pregnancy which may assist in the design of feeding strategies and food rations for military women.

6. METHODS

Study Design

The effect of physical activity level on changes in physical fitness, weight, FFM, fat mass, and energy expenditure will be evaluated through a complete reproductive cycle in sixty-eight women. Women will be studied prior to conception, at each trimester, and at 2, 6 and 24 wk postpartum.

Table 4. Study design

	Pregnancy				Postpartum		
Study variables	0	8wk	22wk	36wk	2wk	6wk	24wk
Anthropometry	x	x	x	x	x	x	x
Hydrodensitometry	x	x	x	x	x		x
TBK	x	x	x	x	x		x
DEXA	x				x	x	x
TBN	x				x		x
TBW		x			x		
TEE/TBW	x		x	x			x
24-h calorimetry	x	x	x	x			x
Physical fitness	x	x	x	x		x	x
Iron status	x	x	x	x		x	x

Subjects

Sixty-eight women will be enrolled, stratified by pre-pregnancy BMI. An upper BMI limit of 24.0 was designated in accordance with military weight standards. However, we are enrolling women with BMI>24, to describe women in the military in noncompliance of weight standards. Subjects will be healthy, physically-active, nonsmoking, ages 18-39 years, parity not greater than 4, no chronic medications or alcohol/drug abuse. Health history should be unremarkable (i.e., normotensive, glucose tolerant, nonanemic and euthyroid).

Methodology

Anthropometry. Maternal body weight to the nearest 0.1 kg will be measured with a digital balance (Scale-Tronix, Dallas TX). Height to the nearest 1 mm will be measured with a stadiometer (Holtain, Ltd, Crymmych, Pems, UK). The circumferences of the head, chest, upper arm, forearm, wrist, neck, abdomen, thigh, and calf will be measured to the nearest 1 mm in duplicate with a metal tape. These sites include those currently used in military equations to predict body fat. Skinfold thicknesses will be measured to the nearest 0.5 mm in duplicate with a Lange skinfold caliper (Cambridge Scientific Industries, Cambridge, MD) at the following sites: triceps, biceps, subscapular, thigh, and suprailiac.

The U.S. Army, Navy and Air Force equations used to predict the body fat of women will be compared against other body composition models.

Table 5. Fat mass prediction equations for the U.S. Army, Navy, and Air Force servicewomen(7)

U.S. Army

$$\text{FM}(\%) = 105.3 \times \log_{10}(\text{weight}) - 0.20 \times \text{waist} - 0.533 \times \text{neck} - 1.574 \times \text{forearm} + 0.173 \times \text{hip} - 0.515 \times \text{height} - 35.6$$

U.S. Navy

$$\text{Density} = -0.35 \times \log_{10}(\text{abdomen I} + \text{hip} - \text{neck}) + 0.221 \times \log_{10}(\text{height}) + 1.296$$

$$\text{FM}(\%) = 100 \times [(4.95/\text{density}) - 4.5]$$

U.S. Air Force

$$\text{FFM}(\text{kg}) = 1.619 \times \text{forearm} + 0.311 \times \text{height} - 47.76$$

$$\text{FM}(\%) = 100 \times (\text{weight} - \text{FFM})/\text{weight}$$

Weight is in kg; height and body circumferences are in cm.

Note: As of 1996 the Air Force adopted the Navy equations for prediction of fat mass.

Hydrodensitometry. An underwater weighing system utilizing "force cube" transducers (Precision Biomedical Systems, Inc., State College, PA) will be used for body density measurements (52). Each subject will be requested to urinate, defecate, shampoo, shower, change to a swimming suit, and then submerge herself and exhale maximally while her body weight in the water is being measured. Residual lung volume will be measured using the simplified nitrogen washout method (53). Body density will be calculated from body weights in and out of the water and residual lung volume.

Total Body Potassium (TBK). Total body ^{40}K content of each subject will be measured using the CNRC low-background whole-body counter. The CNRC counting system consists of a total of 30 NaI(Tl) detectors (each 10 cm x 10 cm x 45 cm) for a total detection volume of 135,000 cc. The detectors are arranged into two arrays positioned above and below the bed with the subject in a supine position. The subject will lie supine for 15 minutes while the body's natural

gamma ray signal is recorded. The gamma signal is directly proportional to the amount of potassium in the body. The precision of the ^{40}K counting is <1% in adults.

Dual Energy X-ray Absorptiometry (DEXA). Composition of the total body and major subregions will be measured using a Hologic QDR 2000W system (Hologic, Inc., Madison, WI). Subregions include the head, thoracic spine, ribs, lumbar spine, pelvis, arms, and legs. The whole body scan takes approximately 15 minutes with the subject lying supine. The low dose (<0.01 mSv) has allowed for IRB approval of research measurements in healthy individuals. Over a 2 y period the average precision for bone mineral density using the spine phantom was $\pm 0.6\%$.

Total Body Nitrogen (TBN). Prompt-Gamma Activation Analysis will be used to measure TBN. The subject is placed in a very weak neutron beam: neutrons interact with body tissues and generate a gamma signal that can be detected external to the body. This technique induces activities of interest that are very short-lived (less than 1 μsec) which requires the detection system to be included in the irradiator assembly. Two shielded, collimated AmBe sources provide a bilateral beam through which the subject is scanned. Four large volume NaI(Tl) detectors with custom designed neutron/gamma shielding are positioned at 90° to both the bed and sources. The scan time is about 15 min; the dose is less than 0.3 mSv (comparable to a chest x-ray). In pigs, the *in vivo* precision was determined to be 3.5% for body nitrogen.

Muscle and Nonmuscle Mass. In the nonpregnant women TBK and TBN will be used to estimate the relative amounts of protein in muscle and nonmuscle components of the body and the mass of each component (54). The principle underlying this approach is that the K/N ratio for muscle is higher than that of nonmuscle tissues (3.03 vs 1.33 meq/g). Assuming the values of 30 g N/kg and 91 meq K/kg muscle, and 36 g N/kg and 48 meq K/kg nonmuscle, total muscle mass is equal to $(\text{K}-1.33\text{N})/51.0$ and total nonmuscle mass is equal to $(3.03 \text{ N}-\text{K})/61.2$.

Body Composition Models. The Fuller (55) four-compartment model that combines total body water (TBW), body density and DEXA measurements will be used to compute fat-free mass (FFM) and fat mass (FM). A constant ratio of bone mineral to non-osseous mineral (0.8191:0.1809) is assumed. The equation used is: $\text{FM}(\text{kg}) = 2.747 \text{ body volume} - 0.710 \text{ TBW} + 1.460 \text{ total body bone ash} - 2.050 \text{ weight}$. Gestational values for total body bone ash will be linearly interpolated from pre-pregnancy and day 15 postpartum measurements. Regional fat deposition during pregnancy and mobilization postpartum will be studied through all reproductive phases using anthropometry and DEXA. Subregions described by DEXA include the head, thoracic spine, ribs, lumbar spine, pelvis, arms, and legs.

Total Body Water (TBW). After collection of baseline saliva samples, 40 mg $^2\text{H}_2\text{O}/\text{kg}$ in the form of water will be administered orally at 8 and 36 wk of gestation, and 2 and 24 wk postpartum. The ^2H abundance in saliva samples will be measured by gas-isotope-ratio mass spectrometry. TBW will be calculated from the elevation of ^2H abundance in the 4-h and 6-h postdose samples. TBW will be determined from $^2\text{H}_2^{18}\text{O}$ dilution prior to pregnancy and at 22 wk gestation, and at 24 wk postpartum (see TEE).

Total Energy Expenditure. Total energy expenditure (TEE) over a 14-day period will be calculated from the fractional turnover rates of ^2H and ^{18}O following oral ingestion of 100 mg/kg $^2\text{H}_2\text{O}$ and 125 mg ^{18}O as water (56). Isotope dilution spaces will be used to compute TBW. Baseline saliva samples will be collected from each subject. Subsequently, one daily saliva

sample will be collected by each subject at home for the next 14 days. The ^2H and ^{18}O abundances of the saliva samples will be measured by gas-isotope-ratio mass spectrometry. Carbon dioxide production (VCO_2) will be calculated from the dilution spaces and fractional turnover rates of ^2H and ^{18}O using the multipoint slope-intercept method of calculation. Fractionated insensible water losses will be calculated from ventilatory volume and body surface area, both expressed as functions of CO_2 production. Respiratory quotient will be computed from the food quotient based on dietary records (57). TEE will be calculated using the Weir equation (58).

Room Respiration Calorimetry. Oxygen consumption (VO_2) and VCO_2 of mothers will be measured and monitored continuously in a room-sized indirect calorimeter for 24-h (59). Energy expenditure will be calculated from VO_2 and VCO_2 . Performance tests with N_2 and CO_2 infusions demonstrated that the accuracy of individual measurements of VO_2 and VCO_2 were 3%. System response to a step change exceeded 90% in 4 min. Sleeping metabolic rate (SMR), and basal metabolic rate (BMR) will be extracted from specific time periods. BMR will be measured for 40 minutes while the subject lies quietly 30 min after awaking and voiding. Fat and carbohydrate net utilization will be computed using 24-h excretion rates of urinary nitrogen according to Livesey (60).

The heart rate of the subject will be monitored and recorded continuously by telemetry (Dynascope 3300 Telemetry System, Fukuda Denshi America). During the 24-h period in the calorimeter, subjects will be asked to adhere to a schedule of feeding, sleeping and exercise times. Energy intake will be controlled according to body weight. Subjects will walk twice for 10 minute each at 2.5 and 3.5 mph, no grade, on a treadmill.

Physical Activity. Physical activity level, our major independent variable, will be determined by combining the doubly-labeled water method with respiration calorimetry. Physical activity level will be quantified in terms of MJ/d as the difference between TEE and BMR. Physical activity level will be described qualitatively using the Minnesota Leisure Time Activity Scale (61) combined with the Health Insurance Plan (HIP) Questionnaire for assessment of occupational activity (62).

Physical Fitness. Maximal VO_2 will be measured in nonpregnant women who will undergo a stepwise increase in exercise intensity until volitional fatigue is achieved (3-Corval 400, LODE B.V., Groningen, Holland and 2-Combi Cycle EX80, Combi, Co., LTD. Tokyo). Subjects will cycle for 4 min at 50 watts for steady state determination of VO_2 , and then the workload will be increased by 25 watts every minute. VO_2 consumption will be measured continuously via the open circuit technique with a metabolic cart (SensorMedics 2900; Yorba Linda, CA). Heart rate and blood pressure will be monitored. Steady-state heart rate and VO_2 values will be used to estimate $\text{VO}_{2\text{max}}$.

Submaximal VO_2 also will be measured in the room respiration calorimeter, unimpeded by a mouthpiece apparatus. In the morning and afternoon women will walk for 20 minute at 2.5 mph, no grade, on a treadmill (905E, Precor, Bothell, WA); heart rate will not be allowed to exceed 140 bpm in pregnant women.

Strength. Prior to the 1 RM strength assessments, the subject will practice using the equipment to become familiar with the proper exercise techniques and to prevent injuries. The

upper and lower body 1 RM strength tests will be done utilizing the Cybex Smith Press and the Cybex Latissimus Pulldown (upper body), and the Cybex Modular Leg Press and the Cybex Leg Extension (lower body). The 1 RM is defined as the maximum amount of weight that can be lifted successfully one time only. Starting with a weight used in the practice session, the subjects will attempt lifts with gradually increasing weight (10% at first, decreasing to 5 and 2.5% as difficulty becomes evident). Successive attempts will be made with a 90-s rest between attempts until failure occurs. These measurements will be done at the Texas Children's Hospital Wellness Center within the Department of Pediatrics.

Infant Outcome. Birthweight, length and gestational age will be recorded from medical records.

Biochemical Analysis. A 12-h fasting blood sample will be obtained for the following analyses. A Complete Blood Count and Differential including hemoglobin and hematocrit will be performed by Smith Kline Beecham Clinical Laboratories. Standard techniques of flow cytometry, automated cytochemistry and microscopy are used. Serum iron and total iron binding capacity will be measured using atomic absorption spectrophotometry (Perkin-Elmer Corp., Norwalk, Conn). Serum ferritin will be determined by ^{125}I -radioimmunoassay (Diagnostic Products Corp., CA). To correct calorimetry data, 24-h urinary nitrogen will be determined by the Kjeldahl method (Tecator, Höganäs, Sweden).

Statistical Analysis. Analysis of variance and covariance with repeated measures will be used to test our hypothesis. The grouping factor will be pre-pregnancy BMI stratification. The within factors will be pregnancy status (antepartum or postpartum), and time (levels= 0, 8, 22, 36 wk gestation; 2, 6 and 24 wk postpartum). The major independent variable to be tested is physical activity level. The dependent variables to be analyzed under this model will be weight, FFM, fat mass, energy expenditure, and physical fitness. Covariates to be included in the model are age, parity, iron status and infant feeding mode. Pre-pregnancy BMI will be treated also as a continuous variable in a separate analysis. We will also use multiple regression analysis to investigate relationships between the various dependent variables. Statistical analyses will be performed using BMDP (63) and Minitab (64) statistical packages. Microsoft ACCESS will be used for data management.

7. RESULTS and DISCUSSION

Preliminary Data Presentation:

Preliminary data will be presented on 82 women enrolled into the study. **Although interesting trends are emerging, the number of women who have completed the entire study are too few to make firm conclusions regarding the effects of physical activity level on pregnancy-induced changes in weight, body composition, physical fitness and energy requirements, or to assess postpartum return to weight and physical fitness standards.** The sample has been subdivided according to the women's prepregnancy BMI. The low BMI group

is defined as BMI<19.8, the normal BMI group as BMI >19.8 and <26.0, and the high BMI group as BMI>26.0. Military-eligible women fall into the low and normal BMI groups, while women in the high BMI group exceed military weight standards and would not be eligible for military service. However, since at any given time the weights of many women in the military exceed weight standards, it is important to recognize that some women enter pregnancy "out of standard," compounding the difficulty of losing weight postpartum.

Subject Description:

A total of 853 women responded to recruiting initiatives, of whom 224 passed the screening criteria and accepted our invitation to tour the CNRC facility with their spouse (or partner) and received an overview of the study. To date, 82 women have been enrolled into the "Fit for Life" study. The sample consists of 59 Caucasian, 13 Afro-American, and 10 Hispanic women. The ages of the women range from 19 to 39 y. Of the 82 women enrolled, 44 have become pregnant, and 29 have delivered their infants. Eighteen women have completed the entire protocol through 6 mo postpartum. Thirteen women discontinued the study because of fertility problems, miscarriages, multiple births or lost to follow-up.

Reproductive History:

Reproductive history indicates normal menses, except in a few cases with prolonged use of oral contraceptives. Twenty-two women have been asked to return for an abbreviated list of baseline measurements, because of failure to conceive within one year.

Table 6. Reproductive history		
N		82
Maternal age	y	30.4 ± 4.3*
Menarche age	y	12.9 ± 1.4
Menses interval	d	29.1 ± 4.3
Menses duration	d	4.5 ± 1.1
Gravidity		0.7 ± 1.0
Parity		0.4 ± 0.6
Education	y	16.8 ± 2.3
Ethnicity	W/B/H	59/13/10

*Mean ± SD

Pregnancy Outcome:

Of the 29 deliveries, all were term, healthy infants except for four preterm infants born between 33-36 weeks of gestation. Birthweight and gestational age tended to be lower in the low

BMI group (3.1 ± 0.4 kg, 38.3 ± 2.2 wk) compared with the normal BMI group (3.7 ± 0.5 kg, 39.0 ± 1.4 wk) and the high BMI group (3.7 ± 0.3 kg, 40.0 ± 0.8 wk).

Table 7. Pregnancy Outcome				
		Male	Female	All
N		15	14	29
Gestational age	wk	$39.1 \pm 1.4^*$	38.8 ± 1.8	39.0 ± 1.6
Maternal weight gain	kg	15.6 ± 4.5	15.5 ± 5.3	15.5 ± 4.8
Birthweight	kg	3.6 ± 0.5	3.4 ± 0.5	3.5 ± 0.5
Birth length	cm	51.0 ± 2.2	50.4 ± 2.0	50.7 ± 2.1
Apgar score 1 min		8.0 ± 0.9	8.3 ± 0.5	8.2 ± 0.7
Apgar score 5 min		8.8 ± 0.8	9.1 ± 0.3	8.9 ± 0.6

*Mean \pm SD

Iron Status:

Iron status will be assessed throughout the reproductive cycle, because of its potential effect on pregnancy outcome, work capacity, and physical fitness. Iron metabolism and erythrocyte indices are altered by the physiological changes of normal pregnancy. Serum iron decreases with increasing duration of pregnancy due to plasma volume expansion. Serum transferrin increases by ~ 2.4 fold due to estrogen-stimulated hepatic protein synthesis; iron saturation accordingly decreases. Serum ferritin decreases as iron stores are used for expansion of erythrocyte mass. Because of these changes in iron metabolism, it is difficult to distinguish anemia due to iron deficiency from dilutional anemia. To provide a more sensitive indicator of iron deficiency in pregnancy, we are using an EIA assay for serum transferrin receptor (Ramco Laboratories Inc.). In contrast to ferritin, serum transferrin receptor is not elevated with inflammation or infection. Any elevation of serum transferrin receptor during pregnancy is due to maternal iron deficiency. Serum ferritin, transferrin and transferrin receptor will be monitored throughout the reproductive cycle to evaluate the impact of iron status on pregnancy outcome and postpartum recovery. The data also will be analyzed for evidence of an effect of iron deficiency on basal energy expenditure and submaximal work performance.

Prior to pregnancy, there is no evidence of iron deficiency or anemia in these women, based on normal values for hemoglobin, hematocrit, serum iron, iron binding capacity and percent iron saturation. Serum ferritin, an indicator of iron stores, and transferrin receptor, an index of tissue iron need, also fell within the normal limits for all women before pregnancy. The transferrin receptor initially decreases in pregnancy due to hemodilution and then increases in the third trimester in all groups. The increasing levels of transferrin receptor with advancing pregnancy and postpartum indicate the appearance of mild iron deficiency in some women.

Table 8. Iron status													
Low BMI Group		Pre-pregnancy		8 wk pregnancy		22 wk pregnancy		36 wk pregnancy		6 wk postpartum		24 wk postpartum	
		n=17		n=10		n=8		n=6		n=5		n=5	
Serum iron	mcg/dl	98.71 ± 30.08		112.00 ± 24.56		114.88 ± 26.34		70.83 ± 38.50		76.60 ± 35.46		88.60 ± 54.55	
Iron binding capacity	mcg/dl	302.82 ± 41.72		295.50 ± 29.80		335.88 ± 56.13		407.33 ± 52.03		285.00 ± 56.55		302.40 ± 48.21	
Iron saturation	%	33.47 ± 12.44		38.20 ± 9.24		35.63 ± 11.58		17.67 ± 10.48		29.00 ± 15.05		31.00 ± 20.55	
White blood cell count	x10 ⁹ /L	5.10 ± 1.20		8.14 ± 2.10		9.08 ± 1.98		9.60 ± 1.73		6.15 ± 1.38		5.78 ± 1.43	
Red blood cell count	x10 ¹² /L	4.38 ± 0.34		4.18 ± 0.30		3.71 ± 0.32		3.74 ± 0.34		4.21 ± 0.36		4.46 ± 0.27	
Hemoglobin	g/dl	13.65 ± 0.79		13.08 ± 0.80		11.93 ± 0.79		11.82 ± 1.36		12.50 ± 0.76		13.06 ± 0.98	
Hematocrit	%	40.40 ± 2.58		38.44 ± 2.85		35.05 ± 2.40		35.05 ± 3.97		37.27 ± 2.39		38.54 ± 2.36	
Mean corpuscular volume	fL	91.92 ± 3.09		92.01 ± 3.38		94.66 ± 4.84		94.22 ± 7.78		89.00 ± 8.55		86.58 ± 6.37	
Mean corpuscular hemoglobin	pg	31.09 ± 1.04		31.35 ± 1.37		32.24 ± 1.83		31.65 ± 2.77		29.90 ± 3.45		29.36 ± 2.59	
Mean corpuscular hemoglobin concentration	%	33.11 ± 2.50		34.05 ± 0.68		34.00 ± 0.32		33.60 ± 0.61		33.55 ± 1.04		33.84 ± 0.53	
Ferritin	ng/ml	52.00 ± 26.33		72.40 ± 34.11		32.25 ± 17.38		14.52 ± 6.81		65.80 ± 41.01		59.40 ± 50.94	
Transferrin receptor	mg/ml	4.37 ± 1.00		4.08 ± 1.27		3.80 ± 0.88		7.10 ± 3.26		6.81 ± 3.57		6.01 ± 3.00	
Normal BMI Group		Pre-pregnancy		8 wk pregnancy		22 wk pregnancy		36 wk pregnancy		6 wk postpartum		24 wk postpartum	
		n=38		n=24		n=24		n=17		n=15		n=10	
Serum iron	mcg/dl	107.18 ± 31.70		117.04 ± 21.52		108.79 ± 33.92		124.94 ± 45.32		88.60 ± 28.34		89.90 ± 25.52	
Iron binding capacity	mcg/dl	318.61 ± 46.34		305.17 ± 36.40		379.58 ± 59.24		454.53 ± 99.80		314.53 ± 41.62		302.70 ± 45.54	
Iron saturation	%	33.82 ± 8.83		38.67 ± 7.72		28.75 ± 8.44		28.59 ± 11.14		28.33 ± 8.52		29.50 ± 8.24	
White blood cell count	x10 ⁹ /L	6.00 ± 1.86		8.18 ± 2.35		10.07 ± 2.64		10.50 ± 3.11		5.74 ± 0.93		6.16 ± 1.39	
Red blood cell count	x10 ¹² /L	4.45 ± 0.31		4.22 ± 0.38		3.80 ± 0.32		3.91 ± 0.46		4.20 ± 0.32		4.58 ± 0.37	
Hemoglobin	g/dl	13.69 ± 0.81		13.25 ± 1.03		12.07 ± 0.95		12.32 ± 1.17		12.84 ± 0.84		13.82 ± 0.45	
Hematocrit	%	40.36 ± 2.51		38.80 ± 3.00		35.47 ± 2.74		36.50 ± 3.51		38.14 ± 2.29		41.10 ± 1.35	
Mean corpuscular volume	fL	90.86 ± 4.14		92.02 ± 3.31		93.46 ± 4.06		93.54 ± 4.68		90.86 ± 4.75		87.01 ± 9.04	
Mean corpuscular hemoglobin	pg	30.82 ± 1.48		31.45 ± 1.16		31.80 ± 1.49		31.54 ± 1.75		30.63 ± 1.68		30.32 ± 1.84	
Mean corpuscular hemoglobin concentration	%	33.89 ± 0.56		34.15 ± 0.60		34.00 ± 0.78		33.69 ± 0.66		33.67 ± 0.54		33.65 ± 0.33	
Ferritin	ng/ml	48.84 ± 39.30		84.12 ± 59.22		44.42 ± 51.43		18.69 ± 7.09		46.63 ± 27.03		39.30 ± 17.10	
Transferrin receptor	mg/ml	4.63 ± 1.31		4.45 ± 1.23		4.56 ± 1.59		5.36 ± 1.32		5.73 ± 1.83		5.35 ± 1.46	

Table 8. Iron status (cont)

High BMI Group		Pre-pregnancy n=18	8 wk pregnancy n=2	22 wk pregnancy n=3	36 wk pregnancy n=4	6 wk postpartum n=4	24 wk postpartum n=3
Serum iron	mcg/dl	104.50 ± 31.20	119.00 ± 14.14	88.33 ± 13.05	91.50 ± 38.70	50.25 ± 9.81	58.67 ± 14.01
Iron binding capacity	mcg/dl	321.61 ± 35.52	328.50 ± 4.95	337.33 ± 21.03	414.00 ± 24.26	346.25 ± 22.20	338.33 ± 49.74
Iron saturation	%	32.17 ± 9.09	36.50 ± 3.54	26.00 ± 5.20	21.75 ± 8.77	14.50 ± 3.42	18.33 ± 7.09
White blood cell count	x10 ⁹ /L	6.01 ± 1.55	9.30 ± 2.83	11.08 ± 4.30	10.40 ± 2.41	6.48 ± 1.71	5.10 ± 0.62
Red blood cell count	x10 ¹² /L	4.60 ± 0.35	4.35 ± 0.81	3.76 ± 0.30	3.90 ± 0.36	4.22 ± 0.35	4.38 ± 0.16
Hemoglobin	g/dl	13.87 ± 0.76	13.35 ± 2.19	11.95 ± 0.93	12.05 ± 1.09	12.35 ± 0.98	13.10 ± 0.40
Hematocrit	%	41.26 ± 2.62	39.05 ± 7.28	34.85 ± 2.67	35.88 ± 3.70	37.43 ± 3.14	41.40 ± 0.95
Mean corpuscular volume	fL	89.70 ± 4.16	89.75 ± 0.21	92.50 ± 0.90	91.80 ± 2.92	88.73 ± 4.25	94.50 ± 3.58
Mean corpuscular hemoglobin	pg	30.24 ± 1.57	30.90 ± 0.71	31.73 ± 0.60	30.88 ± 1.18	29.33 ± 1.28	30.00 ± 0.26
Mean corpuscular hemoglobin concentration	%	33.67 ± 0.74	34.35 ± 0.64	34.28 ± 0.31	33.63 ± 0.64	33.03 ± 0.25	31.73 ± 0.99
Ferritin	ng/ml	56.89 ± 42.06	59.00 ± 45.25	40.53 ± 44.72	25.25 ± 18.77	15.25 ± 4.65	20.50 ± 14.85
Transferrin receptor	mg/ml	6.12 ± 1.98	4.32 ± 1.80	4.03 ± 1.24	6.11 ± 2.57	6.88 ± 2.25	8.53 ± 2.70

*Mean±SD

Anthropometry

The anthropometric measurements reflect a wide array of body sizes. Prior to conception, the mean weight was 50.6 ± 3.5 kg for the low BMI group, 60.5 ± 6.0 kg for the normal BMI group, and 82.0 ± 9.4 kg for the high BMI group. Anthropometric measurements will be used to monitor gestational weight gain/postpartum weight loss, and site-specific deposition/postpartum mobilization of subcutaneous body fat. In the 29 women who have delivered, the total gestational weight gain at delivery was 15.5 ± 4.8 kg. Maternal weight gain tended to be higher in the normal BMI group (16.0 ± 5.3 kg) than in the low (14.0 ± 4.2 kg) and high BMI (14.3 ± 3.2 kg) groups.

Low BMI Group		Pre-pregnancy n=18	8 wk pregnancy n=11	22 wk pregnancy n=8	36 wk pregnancy n=7	2 wk postpartum n=7	6 wk postpartum n=7	24 wk postpartum n=5
Weight	kg	50.65 ± 3.51*	50.43 ± 3.87	56.06 ± 3.41	61.10 ± 2.14	53.36 ± 3.08	52.60 ± 3.79	50.90 ± 5.04
Height	cm	164.23 ± 4.95	162.75 ± 4.45	162.50 ± 5.32	162.78 ± 5.10	160.30 ± 6.20	157.65 ± 7.86	160.30 ± 7.03
BMI	kg/m ²	18.77 ± 0.84	19.02 ± 0.94	21.24 ± 1.11	23.15 ± 1.41	20.82 ± 1.64	21.24 ± 2.02	19.80 ± 1.51
Circumferences:								
Neck	cm	30.51 ± 1.41	29.71 ± 0.93	29.95 ± 0.86	30.19 ± 0.78	29.93 ± 0.63	30.17 ± 0.84	30.30 ± 1.19
Chest	cm	82.42 ± 3.11	84.70 ± 2.91	89.06 ± 3.09	92.07 ± 2.78	88.27 ± 2.05	88.87 ± 2.36	86.56 ± 3.50
Waist	cm	64.27 ± 2.78	66.16 ± 2.65	75.40 ± 4.62	87.47 ± 3.60	72.79 ± 3.82	71.76 ± 4.60	67.86 ± 3.62
Hip	cm	88.79 ± 3.29	88.25 ± 3.01	92.94 ± 3.88	95.39 ± 4.22	92.87 ± 4.56	92.53 ± 4.35	90.44 ± 4.98
Thigh	cm	44.29 ± 2.65	43.46 ± 2.64	45.51 ± 2.56	46.46 ± 1.45	45.43 ± 2.24	44.54 ± 2.92	43.56 ± 3.95
Calf	cm	32.78 ± 1.91	32.15 ± 1.91	33.03 ± 1.79	33.24 ± 0.86	31.67 ± 1.23	31.60 ± 1.30	31.70 ± 1.79
Wrist	cm	13.91 ± 0.51	13.56 ± 0.63	13.69 ± 0.60	13.89 ± 0.45	13.53 ± 0.61	13.66 ± 0.53	13.74 ± 0.51
AF Forearm	cm	21.87 ± 1.26	21.46 ± 1.20	21.84 ± 0.90	22.39 ± 0.56	21.64 ± 0.92	21.60 ± 0.95	21.42 ± 1.19
Army forearm	cm	22.12 ± 1.28	21.65 ± 1.30	21.96 ± 1.01	22.51 ± 0.61	22.34 ± 0.95	21.79 ± 1.06	21.52 ± 1.30
Upper arm	cm	23.83 ± 1.72	23.85 ± 1.68	24.99 ± 1.71	25.46 ± 1.74	24.29 ± 2.84	24.84 ± 1.92	24.26 ± 1.71
Skinfold thicknesses:								
Triceps	mm	10.93 ± 3.73	12.60 ± 4.23	15.03 ± 6.74	14.23 ± 6.03	13.40 ± 6.52	14.09 ± 6.73	12.84 ± 3.58
Biceps	mm	4.11 ± 2.32	3.91 ± 1.22	4.38 ± 1.54	4.60 ± 1.94	4.13 ± 1.55	3.71 ± 1.01	3.82 ± 0.83
Subscapular	mm	8.56 ± 1.98	8.49 ± 1.57	12.30 ± 4.83	11.19 ± 4.69	13.56 ± 6.05	12.11 ± 5.86	10.08 ± 3.56
Suprailiac	mm	9.64 ± 4.29	11.35 ± 6.89	17.11 ± 8.96	17.09 ± 7.66	17.36 ± 9.04	15.19 ± 8.67	12.24 ± 5.67
Thigh	mm	19.07 ± 5.91	20.11 ± 7.51	22.98 ± 9.80	21.37 ± 8.97	23.37 ± 11.06	22.33 ± 10.87	17.06 ± 6.56
Sagittal diameter	cm	13.11 ± 0.81				14.92 ± 1.43	15.17 ± 1.66	13.70 ± 0.92
Normal BMI Group								
		Pre-pregnancy n=40	8 wk pregnancy n=24	22 wk pregnancy n=23	36 wk pregnancy n=17	2 wk postpartum n=17	6 wk postpartum n=17	24 wk postpartum n=10
Weight	kg	60.49 ± 6.04	61.13 ± 6.66	64.93 ± 7.26	72.86 ± 8.22	66.29 ± 7.09	65.20 ± 8.15	60.58 ± 7.43
Height	cm	164.54 ± 5.57	164.54 ± 5.93	164.13 ± 6.13	162.05 ± 9.44	163.91 ± 6.16	162.52 ± 8.74	162.99 ± 8.18
BMI	kg/m ²	22.32 ± 1.60	22.55 ± 1.77	24.08 ± 2.12	28.08 ± 3.00	24.73 ± 2.14	24.70 ± 2.58	22.77 ± 1.88
Circumferences:								
Neck	cm	31.49 ± 1.43	31.67 ± 1.60	31.40 ± 1.60	32.17 ± 1.66	32.08 ± 1.43	32.56 ± 1.28	31.96 ± 1.66
Chest	cm	88.96 ± 4.45	90.73 ± 4.15	95.12 ± 4.89	97.79 ± 5.50	96.19 ± 5.33	95.47 ± 4.96	91.44 ± 5.30
Waist	cm	70.58 ± 4.25	72.26 ± 4.07	80.83 ± 5.02	93.91 ± 4.33	78.95 ± 3.18	77.32 ± 4.02	72.72 ± 4.28
Thigh	cm	49.57 ± 3.02	49.02 ± 3.48	49.15 ± 5.21	51.98 ± 3.80	50.91 ± 3.63	50.72 ± 3.74	49.86 ± 3.10
Calf	cm	35.57 ± 2.25	35.79 ± 2.21	35.84 ± 2.13	37.22 ± 2.26	36.29 ± 2.11	36.17 ± 2.48	35.66 ± 2.34

Table 9. Anthropometry (cont)

Table 9. Anthropometry (cont.)														

*Mean ± SD

Body Composition

Standard 2-component body composition models based on deuterium dilution, hydrodensitometry, or total body potassium, while applicable prior to conception, are invalid during pregnancy due to the expansion of body fluid compartments. To obtain more accurate estimates of FFM and FM in reproductive women, we have chosen the Fuller 4-component model, which minimizes assumptions regarding the hydration of FFM and the bone mineral content of dry FFM, by incorporating measurements of total body water, body density, and BMC (55). This model also provides more accurate body composition estimates in non-pregnant individuals. A comparison of FM estimated by the standard and multicomponent body composition models is presented in Table 10. Systematic differences between methods in the estimation of fat mass are evident. Based on the Fuller multi-component model, the average gestational fat gain is 5.4 ± 5.4 kg with a wide range (-4.5 to 14.4 kg) between the pre-pregnancy study and 36 wk of pregnancy.

Table 10. Fat mass (FM) estimated by deuterium dilution, hydrodensitometry, total body potassium, DEXA, and skinfold thicknesses, and multi-component models									
Low BMI Group		Pre-pregnancy n=18	8 wk pregnancy n=11	22 wk pregnancy n=8	36 wk pregnancy n=6	2 wk postpartum n=7	6 wk postpartum n=7	24 wk postpartum n=5	
Deuterium dilution:									
Total body water (TBW)	kg	28.99 ± 3.06*	28.50 ± 2.79	30.80 ± 2.23	35.24 ± 3.88	30.16 ± 2.45	29.16 ± 3.06	26.82 ± 3.24	
FM (TBW)	kg	10.79 ± 3.09	10.91 ± 2.98	13.82 ± 3.60	14.87 ± 5.88	13.15 ± 2.21	11.66 ± 2.47	14.16 ± 3.21	
Hydrodensitometry (HD):									
Body Volume	l	48.31 ± 3.39	47.83 ± 3.53	53.33 ± 3.22	58.96 ± 2.96	52.59 ± 3.96	50.93 ± 4.06	48.93 ± 4.84	
FM (HD)	kg	10.99 ± 2.85	11.27 ± 3.01	14.04 ± 3.76	13.71 ± 4.24	13.97 ± 3.99	14.71 ± 4.04	13.33 ± 1.41	
Total body potassium (TBK):									
FM (TBK)	kg	10.58 ± 3.54	11.71 ± 3.52	16.12 ± 5.61	18.94 ± 4.13	13.51 ± 4.96	15.54 ± 4.81	12.04 ± 2.60	
Dual energy x-ray absorptiometry (DEXA):									
FM (DEXA)	kg	10.80 ± 3.14	***	***	***	15.13 ± 5.81	15.78 ± 4.40	13.17 ± 1.54	
Skinfold thickness (Durnin & Womersley):									
FM (SF)	kg	11.27 ± 1.66	11.56 ± 2.16	14.89 ± 2.90	16.43 ± 3.09	14.11 ± 2.96	13.36 ± 3.22	12.14 ± 1.03	
Multi-component models:									
FM-Siri (TBW, HD)	kg	10.93 ± 2.59	11.29 ± 2.85	14.03 ± 3.31	14.47 ± 5.00	13.20 ± 2.85	12.46 ± 2.25	13.88 ± 2.25	
FM-Fuller (TBW, HD, DEXA)	kg	11.40 ± 2.38	11.50 ± 2.93	14.11 ± 3.27	15.19 ± 5.26	13.54 ± 3.30	13.56 ± 0.72	13.94 ± 2.07	
Normal BMI Group									
		Pre-pregnancy n=40	8 wk pregnancy n=24	22 wk pregnancy n=23	36 wk pregnancy n=16	2 wk postpartum n=16	6 wk postpartum n=17	24 wk postpartum n=10	
Deuterium dilution:									
Total body water (TBW)	kg	31.99 ± 3.63	31.97 ± 4.00	33.57 ± 4.12	39.47 ± 3.87	34.63 ± 3.30	33.03 ± 3.85	31.92 ± 5.02	
FM (TBW)	kg	17.00 ± 4.88	17.37 ± 3.46	19.18 ± 4.61	22.17 ± 5.50	20.34 ± 4.41	18.94 ± 4.31	17.49 ± 4.54	
Hydrodensitometry (HD):									
Body Volume	l	58.09 ± 5.40	58.85 ± 6.49	62.81 ± 7.40	72.60 ± 8.05	65.47 ± 7.26	65.03 ± 9.67	57.73 ± 7.19	
FM (HD)	kg	16.75 ± 3.92	16.82 ± 4.05	18.69 ± 4.41	21.55 ± 4.38	20.80 ± 4.95	21.90 ± 5.70	17.46 ± 3.08	

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Table 10. Fat mass (FM) estimated by deuterium dilution, hydrodensitometry, total body potassium, DEXA, and skinfold thicknesses, and multi-component models (cont)

Total body potassium (TBK):									
FM (TBK)	kg	16.40 ± 4.12	17.91 ± 4.17	20.91 ± 4.20	22.81 ± 6.04	20.37 ± 4.98	21.04 ± 5.12	16.29 ± 5.32	
Dual energy x-ray absorptiometry (DEXA):									
FM (DEXA)	kg	17.19 ± 3.77	***	***	***	21.48 ± 5.33	21.58 ± 5.58	18.19 ± 3.96	
Skinfold thickness (Durnin & Womersley):									
FM (SF)	kg	17.30 ± 3.45	18.09 ± 3.75	20.27 ± 4.48	24.86 ± 4.80	21.20 ± 4.54	20.86 ± 4.55	18.09 ± 4.44	
Multi-component models:									
FM-Siri (TBW, HD)	kg	16.99 ± 4.00	17.16 ± 3.62	19.01 ± 4.32	22.22 ± 5.12	20.49 ± 4.16	19.81 ± 4.42	18.03 ± 3.79	
FM-Fuller (TBW, HD, DEXA)	kg	17.17 ± 4.00	17.13 ± 3.64	19.39 ± 4.29	22.24 ± 4.96	20.35 ± 3.99	20.60 ± 5.10	18.03 ± 3.79	
High BMI Group		Pre-pregnancy	8 wk pregnancy	22 wk pregnancy	36 wk pregnancy	2 wk postpartum	6 wk postpartum	24 wk postpartum	n=3
Deuterium dilution:		n=19	n=2	n=4	n=4	n=4	n=3	n=3	
Total body water (TBW)	kg	35.53 ± 5.19	35.69 ± 1.26	37.18 ± 2.44	40.72 ± 1.30	38.09 ± 2.70	36.54 ± 4.34	35.04 ± 3.49	
FM (TBW)	kg	32.54 ± 7.46	31.16 ± 4.20	30.95 ± 9.28	34.96 ± 11.23	25.25 ± 7.31	26.28 ± 7.02	26.65 ± 8.15	
Hydrodensitometry (HD):									
Body Volume	l	80.84 ± 7.68	78.65 ± 3.16	80.04 ± 8.93	86.39 ± 10.82	78.19 ± 10.31	74.82 ± 14.71	73.47 ± 13.58	
FM (HD)	kg	32.02 ± 6.28	29.12 ± 4.53	29.99 ± 5.70	30.25 ± 7.08	29.19 ± 7.32	30.16 ± 8.54	27.76 ± 8.98	
Total body potassium (TBK):									
FM (TBK)	kg	32.87 ± 7.87	31.54 ± 4.95	33.54 ± 7.12	35.76 ± 9.07	30.42 ± 8.87	28.24 ± 8.03	28.79 ± 5.74	
Dual energy x-ray absorptiometry (DEXA):									
FM (DEXA)	kg	34.94 ± 7.58	***	***	***	31.16 ± 8.98	28.44 ± 9.42	30.21 ± 7.73	
Skinfold thickness (Durnin & Womersley):									
FM (SF)	kg	32.12 ± 4.81	30.47 ± 5.18	30.53 ± 6.42	33.51 ± 10.08	28.46 ± 6.82	27.59 ± 7.83	28.78 ± 8.36	
Multi-component models:									
FM-Siri (TBW, HD)	kg	32.62 ± 6.95	30.37 ± 4.33	30.67 ± 7.70	33.49 ± 10.04	25.72 ± 6.83	29.09 ± 8.69	27.21 ± 8.51	
FM-Fuller (TBW, HD, DEXA)	kg	33.19 ± 6.85	33±62	40.43	43.39	26.07 ± 7.04	29.49 ± 8.61	27.50 ± 8.65	

*Mean±SD

Mean pre-pregnancy body fat was 11.4 ± 2.4 kg, or $22.6 \pm 4.3\%$ for the low BMI group, 17.2 ± 4.0 kg, or $28.3 \pm 5.6\%$ for the normal BMI group, and 33.2 ± 6.8 kg, or $39.9 \pm 5.2\%$ for the high BMI group by the Fuller 4-component model (Table 10). FM and % body fat at the pre-pregnancy time point estimated by military equations and by standard and multi-component models are listed in Table 11. Fat mass predicted from military equations depends on different anthropometric sites. The Army equation uses the waist and hip circumferences and builds in BMI, ie. weight and height measurements; the Navy equation predicts density from abdomen, hip and height; the Air Force has adopted the Navy equations. Women in the low and normal BMI groups would be eligible for enrollment into each branch of the Armed Services, according to the currently used Army and Navy equations. Only a few women in the high BMI group would be eligible for enrollment into the Army, and none would qualify for the Navy and Air Force.

Pre-pregnancy FM derived from the Fuller 4-component model and military equations were highly correlated ($r^2 = 0.94-0.96$). Percent FM derived from the Fuller 4-component model and military equations also were significantly correlated, but to a lesser extent ($r^2 = 0.81-0.85$) (Figures 1-3). The obsolete Air Force equation significantly overestimated both the mean FM and % FM, and the Army and Navy equations underestimated mean FM and % FM in all BMI groups. The Army and Navy prediction equations are conservative, in that direct measurement of FM would have rendered more women ineligible for service.

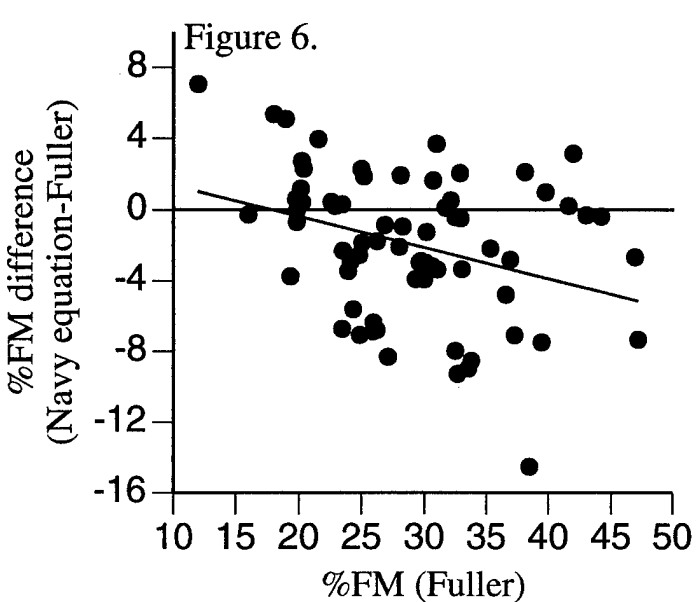
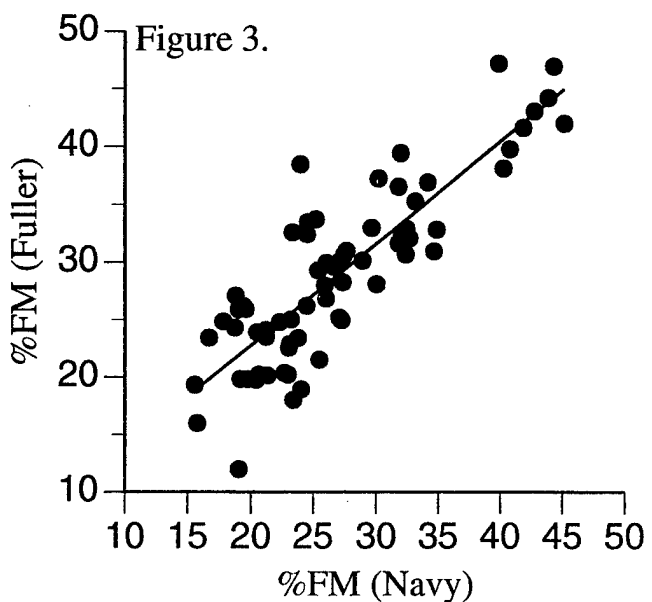
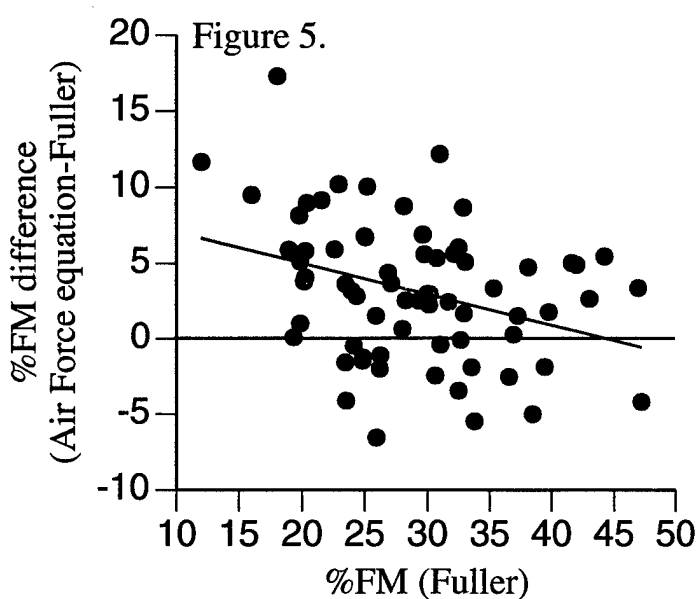
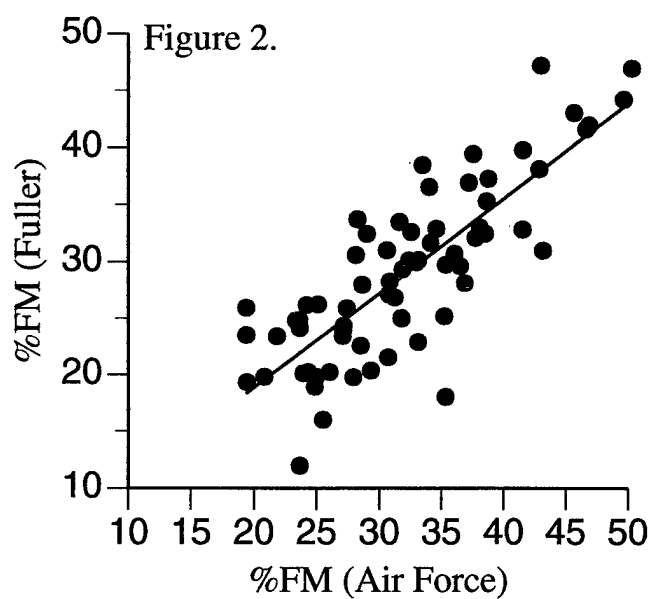
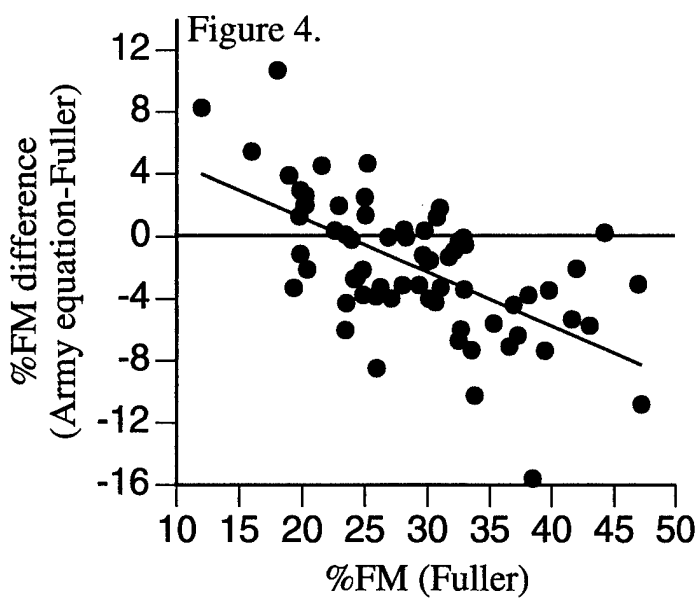
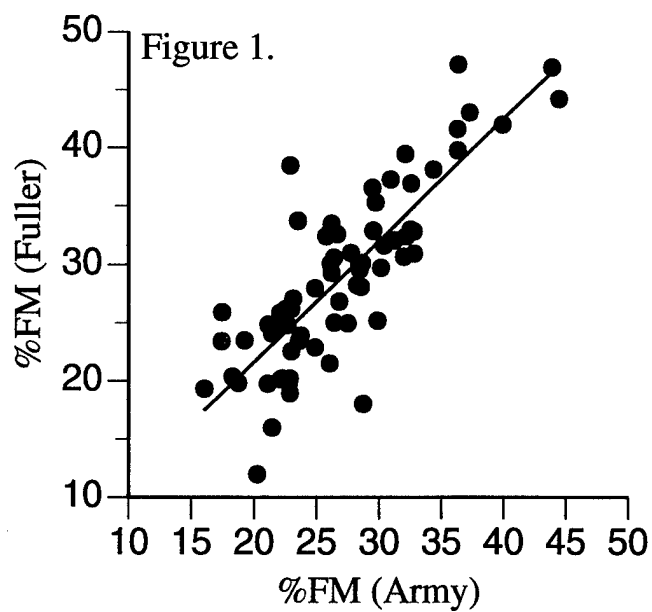
Bland-Altman plots illustrate the differences in pre-pregnancy %FM derived from the Fuller 4-component model and military equations (Figures 4-6). The negative slope indicates that the difference between methods is a function of %FM. The underestimation of %FM was greater in fatter women. The mean differences (or relative biases), $-2 \pm 4\%$ for the Army and Navy equations, and $3 \pm 5\%$ for the Air Force, were statistically significant ($p=0.001-0.006$). The standard deviations or estimations of error imply wide confidence intervals for the prediction of %FM for individuals.

We will also evaluate these predictive equations for use in postpartum women. Further, the effect of gestational weight gain and fat accretion on the ability to return to body fat standards in the 6 months following delivery will be assessed.

Table 11. Body fat mass (FM) predicted from military equations and body composition models at the pre-pregnancy and 24 wk postpartum study intervals

Low BMI Group		Pre-pregnancy n=18	24 wk postpartum n=5		Pre-pregnancy n=18	24 wk postpartum n=5
Army FM	kg	10.48 ± 1.38	12.39 ± 2.22	% FM	20.70 ± 2.38	24.25 ± 2.71
Navy FM	kg	9.80 ± 1.48	11.95 ± 2.57	% FM	19.32 ± 2.32	23.30 ± 3.41
Air Force FM	kg	11.92 ± 1.80	14.13 ± 2.65	% FM	23.53 ± 3.12	27.67 ± 3.52
FM (TBW)	kg	10.79 ± 3.09	14.16 ± 3.21	% FM	21.38 ± 5.86	27.81 ± 5.23
FM (HD)	kg	10.99 ± 2.85	13.33 ± 1.41	% FM	21.69 ± 5.20	26.19 ± 0.97
FM (TBK)	kg	10.58 ± 3.54	12.04 ± 2.60	% FM	20.87 ± 6.74	23.73 ± 4.21
FM (DEXA)	kg	10.80 ± 3.14	13.17 ± 1.54	% FM	21.35 ± 6.02	25.99 ± 3.02
FM-Siri (TBW, HD)	kg	10.93 ± 2.59	13.88 ± 2.25	% FM	21.66 ± 4.83	27.26 ± 3.17
FM-Fuller (TBW, HD, DEXA)	kg	11.40 ± 2.38	13.94 ± 2.07	% FM	22.61 ± 4.33	27.38 ± 2.66
Normal BMI Group		Pre-pregnancy n=40	24 wk postpartum n=10		Pre-pregnancy n=40	24 wk postpartum n=10
Army FM	kg	16.15 ± 3.10	16.81 ± 3.64	% FM	26.58 ± 3.43	27.70 ± 4.53
Navy FM	kg	15.91 ± 3.39	16.65 ± 3.61	% FM	26.12 ± 3.61	27.36 ± 3.98
Air Force FM	kg	19.42 ± 3.90	20.38 ± 4.57	% FM	31.89 ± 4.02	33.42 ± 4.86
FM (TBW)	kg	17.00 ± 4.88	17.49 ± 4.54	% FM	27.76 ± 6.82	28.57 ± 7.09
FM (HD)	kg	16.75 ± 3.92	17.46 ± 3.08	% FM	27.76 ± 5.73	28.87 ± 4.12
FM (TBK)	kg	16.40 ± 4.12	16.29 ± 5.32	% FM	27.18 ± 6.02	26.68 ± 7.81
FM (DEXA)	kg	17.19 ± 3.77	18.19 ± 3.96	% FM	28.39 ± 4.89	30.07 ± 5.55
FM-Siri (TBW, HD)	kg	16.99 ± 4.00	17.80 ± 3.89	% FM	27.94 ± 5.53	29.09 ± 5.70
FM-Fuller (TBW, HD, DEXA)	kg	17.17 ± 4.00	18.03 ± 3.79	% FM	28.31 ± 5.57	29.46 ± 5.45
High BMI Group		Pre-pregnancy n=19	24 wk postpartum n=3		Pre-pregnancy n=19	24 wk postpartum n=3
Army FM	kg	29.34 ± 6.08	24.29 ± 2.62	% FM	35.52 ± 4.15	31.66 ± 1.45
Navy FM	kg	31.75 ± 6.98	27.59 ± 3.58	% FM	38.33 ± 4.81	35.89 ± 1.56
Air Force FM	kg	35.52 ± 7.08	30.20 ± 4.68	% FM	42.95 ± 4.29	39.17 ± 1.39
FM (TBW)	kg	32.54 ± 7.46	26.65 ± 8.15	% FM	39.95 ± 6.57	35.29 ± 4.80
FM (HD)	kg	32.02 ± 6.28	27.76 ± 8.98	% FM	38.45 ± 5.46	36.70 ± 5.66
FM (TBK)	kg	32.87 ± 7.87	28.79 ± 5.74	% FM	39.87 ± 6.61	37.22 ± 3.12
FM (DEXA)	kg	34.94 ± 7.58	30.21 ± 7.73	% FM	42.01 ± 5.40	38.90 ± 5.78
FM-Siri (TBW, HD)	kg	32.62 ± 6.95	27.21 ± 8.51	% FM	39.33 ± 5.47	36.00 ± 5.16
FM-Fuller (TBW, HD, DEXA)	kg	33.19 ± 6.85	27.50 ± 8.65	% FM	39.87 ± 5.23	36.38 ± 5.29

*Mean ± SD



Fat-Free Mass Compartment

In terms of work capacity and physical fitness, the fat-free mass compartment is the metabolically active part of the body. We will monitor changes in FFM during pregnancy and the postpartum period. We will test whether physical activity can maintain a higher level of physical fitness throughout pregnancy and prevent an undesirable loss of muscle mass associated with postpartum weight loss. We will also be able to relate changes in FFM to any changes in strength.

Based on the principle that the K/N ratio for muscle is higher than that of nonmuscle tissues (3.03 vs. 1.33 meq/g), TBK and TBN will be used to estimate the relative amounts of protein in muscle and nonmuscle components of the body and the mass of each component prior to conception and postpartum. Our preliminary results indicate no postpartum accretion of TBK, but a 5% retention of nitrogen due to pregnancy.

Prior to conception, total body bone mineral density of all subjects was within the normal range (1.00 to 1.36). Our preliminary results do not indicate significant pregnancy-induced changes in bone mineral content, adjusted for bone area.

Table 12. Fat-free mass (FFM) compartment determined by total body potassium, DEXA, and prompt-gamma activation

Low BMI Group	Pre-pregnancy n=18	8 wk pregnancy n=11	22 wk pregnancy n=8	36 wk pregnancy n=6	2 wk postpartum n=7	6 wk postpartum n=7	24 wk postpartum n=5
Total body potassium (TBK):							
TBK	g	94.26 ± 10.06	90.91 ± 8.65	92.74 ± 9.89	99.22 ± 9.41	92.99 ± 9.85	91.10 ± 11.89
K40 LBM	kg	40.06 ± 4.27	38.64 ± 3.68	39.42 ± 4.20	42.17 ± 4.00	39.52 ± 4.18	38.72 ± 5.05
Dual energy x-ray absorptiometry (DEXA):							
Bone mineral content (BMC)	kg	2.08 ± 0.18	***	***	***	2.04 ± 0.14	1.93 ± 0.20
Bone mineral density (BMD)	g/cm ²	1.12 ± 0.05	***	***	***	1.10 ± 0.06	1.08 ± 0.06
FFM (DEXA)	kg	39.37 ± 4.16	***	***	***	38.78 ± 4.33	37.36 ± 4.49
Prompt-gamma activation analysis (PGA):							
Total body nitrogen	g	1320 ± 142	***	***	***	1322 ± 183	1286 ± 190
Muscle mass	kg	12.90 ± 3.90	***	***	***	11.72 ± 3.85	12.21 ± 5.34
Nonmuscle mass	kg	25.91 ± 5.41	***	***	***	26.94 ± 6.72	25.53 ± 7.95
Normal BMI Group	Pre-pregnancy n=40	8 wk pregnancy n=24	22 wk pregnancy n=23	36 wk pregnancy n=16	2 wk postpartum n=16	6 wk postpartum n=17	24 wk postpartum n=10
Total body potassium (TBK):							
TBK	g	102.64 ± 12.83	101.10 ± 14.07	102.95 ± 14.50	114.67 ± 17.23	106.03 ± 11.23	105.33 ± 19.12
K40 LBM	kg	43.62 ± 5.45	42.97 ± 5.98	43.75 ± 6.16	48.73 ± 7.32	45.06 ± 4.77	44.77 ± 8.12
Dual energy x-ray absorptiometry (DEXA):							
Bone mineral content (BMC)	kg	2.28 ± 0.30	***	***	***	2.34 ± 0.35	2.24 ± 0.40
Bone mineral density (BMD)	g/cm ²	1.15 ± 0.09	***	***	***	1.16 ± 0.11	1.14 ± 0.10
FFM (DEXA)	kg	42.75 ± 4.68	***	***	***	43.96 ± 4.27	42.11 ± 6.31
Prompt-gamma activation analysis (PGA):							
Total body nitrogen	g	1506 ± 188	***	***	***	1549 ± 204	1535 ± 319
Muscle mass	kg	12.25 ± 3.11	***	***	***	12.18 ± 1.87	13.96 ± 4.24
Nonmuscle mass	kg	31.62 ± 5.34	***	***	***	32.87 ± 5.82	30.99 ± 9.27

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Table 12. Fat-free mass (FFM) compartment determined by total body potassium, DEXA, and prompt-gamma activation (cont)

High BMI Group	Pre-pregnancy n=19	8 wk pregnancy n=2	22 wk pregnancy n=4	36 wk pregnancy n=4	2 wk postpartum n=4	6 wk postpartum n=3	24 wk postpartum n=3
Total body potassium (TBK):							
TBK	112.78 ± 13.78	113.80 ± 5.80	111.80 ± 6.15	121.68 ± 6.67	110.60 ± 10.21	112.90 ± 6.46	112.93 ± 11.16
K40 LBM	47.93 ± 5.86	48.37 ± 2.46	47.52 ± 2.61	51.71 ± 2.83	47.01 ± 4.34	47.98 ± 2.75	48.00 ± 4.74
Dual energy x-ray absorptiometry (DEXA):							
Bone mineral content (BMC)	2.44 ± 0.33	***	***	***	2.47 ± 0.25	2.37 ± 0.18	2.40 ± 0.20
Bone mineral density (BMD)	1.15 ± 0.08	***	***	***	1.18 ± 0.02	1.16 ± 0.02	1.17 ± 0.03
FFM (DEXA)	46.97 ± 5.63	***	***	***	48.06 ± 4.58	47.76 ± 4.90	46.55 ± 4.07
Prompt-gamma activation analysis (PGA):							
Total body nitrogen	1748 ± 208	***	***	***	1774 ± 118		1779 ± 213
Muscle mass	11.73 ± 3.33	***	***	***	9.26 ± 2.06		10.30 ± 1.09
Nonmuscle mass	38.77 ± 6.27	***	***	***	41.56 ± 1.55		40.83 ± 6.05

*Mean ±SD

Energy Expenditure and Substrate Utilization by Room Respiration Calorimetry

Preconceptional baseline levels of energy expenditure and substrate utilization are summarized in Tables 13 and 14. The mean 24-h TEE and heart rates of the women confined to the room calorimeter are representative of sedentary conditions. TEE increases in absolute terms and relative to body weight throughout pregnancy. By 6 mo postpartum TEE has returned to pre-pregnancy baseline. These data will be used to evaluate changes in energy metabolism and their impact on energy requirements throughout the reproductive cycle in women with low to high BMIs.

Table 13. Room respiration calorimetry						
Low BMI Group		Pre-pregnancy	8 wk pregnancy	22 wk pregnancy	36 wk pregnancy	24 wk postpartum
		n=17	n=9	n=6	n=4	n=4
Total energy expenditure (TEE)						
Heart rate	bpm	68.62 ± 9.43*	73.67 ± 6.18	79.46 ± 9.35	88.58 ± 10.24	72.19 ± 3.64
RQ		0.87 ± 0.03	0.89 ± 0.04	0.89 ± 0.03	0.86 ± 0.02	0.89 ± 0.02
TEE	kcal/d	1611 ± 154	1627 ± 175	1739 ± 119	2022 ± 174	1626 ± 120
TEE	kcal/kg/d	31.87 ± 2.65	32.75 ± 2.47	31.55 ± 3.06	33.15 ± 3.53	30.68 ± 3.71
Basal metabolic rate (BMR)						
Heart rate	bpm	63.16 ± 9.42	68.03 ± 5.69	74.61 ± 10.87	75.93 ± 5.97	65.43 ± 5.53
RQ		0.80 ± 0.04	0.80 ± 0.05	0.80 ± 0.05	0.80 ± 0.01	0.80 ± 0.04
BMR	kcal	1193 ± 129	1255 ± 148	1325 ± 106	1507 ± 167	1181 ± 81
BMR	kcal/kg/d	23.57 ± 1.93	25.20 ± 2.55	24.04 ± 2.63	24.66 ± 2.66	22.37 ± 3.33
TEE/BMR		1.35 ± 0.07	1.30 ± 0.07	1.31 ± 0.05	1.35 ± 0.09	1.38 ± 0.07
Sleeping metabolic rate (SMR)						
Heart rate	bpm	60.59 ± 9.28	67.59 ± 6.90	74.14 ± 10.91	81.59 ± 9.34	64.97 ± 3.64
RQ		0.83 ± 0.02	0.85 ± 0.04	0.86 ± 0.03	0.84 ± 0.02	0.85 ± 0.03
SMR	kcal/kg/d	23.17 ± 1.60	24.90 ± 1.51	23.67 ± 2.50	25.01 ± 2.74	22.83 ± 2.58
Normal BMI Group		Pre-pregnancy	8 wk pregnancy	22 wk pregnancy	36 wk pregnancy	24 wk postpartum
		n=39	n=22	n=23	n=15	n=10
Total energy expenditure (TEE)						
Heart rate	bpm	65.62 ± 8.60	68.79 ± 8.72	75.66 ± 8.44	79.85 ± 10.70	62.23 ± 9.75
RQ		0.88 ± 0.02	0.88 ± 0.01	0.88 ± 0.02	0.87 ± 0.02	0.89 ± 0.03
TEE	kcal/d	1780 ± 172	1797 ± 199	1848 ± 166	2192 ± 255	1727 ± 216
TEE	kcal/kg/d	29.08 ± 2.48	29.37 ± 2.40	28.57 ± 2.22	30.66 ± 2.98	28.63 ± 2.46
Basal metabolic rate (BMR)						
Heart rate	bpm	61.71 ± 9.21	65.20 ± 8.88	71.31 ± 9.74	75.54 ± 12.45	56.98 ± 8.31
RQ		0.80 ± 0.04	0.81 ± 0.03	0.81 ± 0.04	0.81 ± 0.06	0.82 ± 0.04
BMR	kcal	1322 ± 118	1362 ± 158	1423 ± 147	1699 ± 196	1316 ± 165
BMR	kcal/kg/d	21.65 ± 2.08	22.29 ± 2.31	21.99 ± 1.74	24.08 ± 2.62	21.85 ± 1.73
TEE/BMR		1.35 ± 0.08	1.32 ± 0.08	1.30 ± 0.07	1.29 ± 0.04	1.31 ± 0.06

Table 13. Room respiration calorimetry (cont)

Sleeping metabolic rate (SMR)						
Heart rate	bpm	57.14 ± 12.40	61.82 ± 8.56	69.34 ± 8.33	74.30 ± 11.13	52.53 ± 17.48
RQ		0.84 ± 0.02	0.83 ± 0.03	0.85 ± 0.04	0.84 ± 0.04	0.85 ± 0.03
SMR	kcal/kg/d	21.08 ± 1.90	21.53 ± 2.14	21.85 ± 1.80	23.88 ± 2.78	21.95 ± 2.03
High BMI Group		Pre-pregnancy n=19	8 wk pregnancy n=2	22 wk pregnancy n=3	36 wk pregnancy n=4	24 wk postpartum n=2
Total energy expenditure (TEE)						
Heart rate	bpm	74.31 ± 7.22	74.38 ± 3.99	81.77 ± 5.88	86.38 ± 6.07	72.99 ± 0.72
RQ		0.86 ± 0.02	0.88 ± 0.01	0.87 ± 0.02	0.86 ± 0.02	0.90 ± 0.00
TEE	kcal/d	2091 ± 188	1984 ± 82	2016 ± 289	2357 ± 285	1782 ± 246
TEE	kcal/kg/d	26.09 ± 1.73	24.78 ± 0.26	25.72 ± 2.39	26.96 ± 2.31	23.95 ± 0.86
Basal metabolic rate (BMR)						
Heart rate	bpm	69.80 ± 8.41	68.78 ± 2.66	76.58 ± 6.83	79.13 ± 7.50	63.90 ± 0.94
RQ		0.81 ± 0.04	0.83 ± 0.06	0.81 ± 0.04	0.79 ± 0.02	0.82 ± 0.03
BMR	kcal	1537 ± 185	1516 ± 31	1543 ± 272	1769 ± 186	1381 ± 117
BMR	kcal/kg/d	19.25 ± 1.56	18.96 ± 0.97	18.97 ± 2.10	20.29 ± 2.00	18.65 ± 1.67
TEE/BMR		1.37 ± 0.11	1.31 ± 0.08	1.41 ± 0.07	1.33 ± 0.05	1.29 ± 0.07
Sleeping metabolic rate (SMR)						
Heart rate	bpm	68.04 ± 7.53	58.87 ± 17.45	72.62 ± 3.04	80.57 ± 4.27	65.42 ± 0.04
RQ		0.83 ± 0.02	0.85 ± 0.01	0.82 ± 0.04	0.83 ± 0.03	0.85 ± 0.04
SMR	kcal/m	1.03 ± 0.16	1.02 ± 0.08	0.94 ± 0.08	1.25 ± 0.13	0.94 ± 0.16
SMR	kcal/kg/d	18.95 ± 1.12	18.32 ± 0.79	17.22 ± 0.56	20.67 ± 1.89	18.22 ± 0.09

*Mean ± SD

Table 14. Substrate utilization estimated from 24-h respiration calorimetry

Low BMI Group		Pre-pregnancy	8 wk pregnancy	22 wk pregnancy	36 wk pregnancy	24 wk postpartum
		n=17	n=10	n=7	n=5	n=5
Protein utilization	g/d	56.5 ± 11.5	76.1 ± 17.6	70.2 ± 11.4	59.8 ± 15.4	76.3 ± 14.3
Carbohydrate utilization	g/d	183.7 ± 30.7	210.3 ± 35.6	231.0 ± 29.5	232.4 ± 26.5	215.0 ± 19.3
Fat utilization	g/d	59.8 ± 18.1	41.1 ± 25.9	47.9 ± 19.8	82.1 ± 14.0	39.3 ± 12.0
Protein utilization	% TEE	16.7 ± 3.5	22.2 ± 5.4	18.9 ± 2.9	13.8 ± 3.2	22.1 ± 4.4
Carbohydrate utilization	% TEE	48.3 ± 8.7	54.6 ± 10.6	55.6 ± 9.2	48.0 ± 5.3	55.3 ± 5.3
Fat utilization	% TEE	34.9 ± 9.0	23.2 ± 13.4	25.4 ± 9.4	38.0 ± 5.1	22.5 ± 5.9
Carbohydrate utilization	%NPEE	58.1 ± 10.6	70.8 ± 16.6	68.7 ± 11.5	55.8 ± 5.7	71.2 ± 7.0
Fat utilization	%NPEE	41.9 ± 10.6	29.2 ± 16.6	31.3 ± 11.5	44.2 ± 5.7	28.8 ± 7.0
Normal BMI Group		Pre-pregnancy	8 wk pregnancy	22 wk pregnancy	36 wk pregnancy	6 mo postpartum
		n=39	n=23	n=22	n=15	n=10
Protein utilization	g/d	62.4 ± 10.9	73.8 ± 18.8	66.5 ± 15.8	71.1 ± 15.9	65.8 ± 15.2
Carbohydrate utilization	g/d	217.5 ± 31.2	217.9 ± 33.4	237.1 ± 41.9	258.2 ± 48.8	227.8 ± 62.7
Fat utilization	g/d	59.0 ± 14.5	54.4 ± 11.0	55.9 ± 19.1	79.9 ± 22.9	47.3 ± 17.1
Protein utilization	% TEE	16.7 ± 2.6	19.6 ± 3.6	17.0 ± 3.5	15.5 ± 3.3	18.2 ± 4.4
Carbohydrate utilization	% TEE	51.7 ± 6.4	51.2 ± 4.8	54.2 ± 8.6	49.8 ± 8.2	55.5 ± 11.1
Fat utilization	% TEE	31.5 ± 6.1	29.1 ± 5.9	28.7 ± 9.0	34.6 ± 8.4	26.3 ± 8.6
Carbohydrate utilization	%NPEE	62.1 ± 7.4	63.9 ± 6.6	65.4 ± 10.5	59.0 ± 9.5	67.6 ± 11.4
Fat utilization	%NPEE	37.9 ± 7.4	36.1 ± 6.6	34.6 ± 10.5	41.0 ± 9.5	32.4 ± 11.4
High BMI Group		Pre-pregnancy	8 wk pregnancy	22 wk pregnancy	36 wk pregnancy	24 wk postpartum
		n=19	n=2	n=3	n=4	n=2
Protein utilization	g/d	81.0 ± 14.6	95.3 ± 39.1	54.5 ± 36.7	71.9 ± 13.9	53.0 ± 35.8
Carbohydrate utilization	g/d	232.6 ± 38.4	240.7 ± 51.1	244.7 ± 74.0	265.7 ± 61.0	259.0 ± 19.8
Fat utilization	g/d	75.5 ± 15.2	53.5 ± 6.2	75.9 ± 9.5	93.4 ± 16.4	46.0 ± 1.2
Protein utilization	% TEE	18.6 ± 3.8	23.1 ± 10.4	13.4 ± 9.3	14.7 ± 3.8	13.6 ± 7.7
Carbohydrate utilization	% TEE	47.0 ± 6.7	51.2 ± 8.6	50.4 ± 9.0	47.4 ± 7.1	61.5 ± 3.6
Fat utilization	% TEE	34.3 ± 5.3	25.7 ± 1.8	36.0 ± 3.0	37.7 ± 4.6	24.8 ± 4.0
Carbohydrate utilization	%NPEE	57.7 ± 7.1	66.4 ± 2.2	58.1 ± 5.0	55.5 ± 6.6	71.3 ± 2.1
Fat utilization	%NPEE	42.3 ± 7.1	33.6 ± 2.2	41.9 ± 5.0	44.5 ± 6.6	28.7 ± 2.1

*Mean ± SD

Abbreviations: EI=energy intake; RQ=respiratory quotient; TEE=total energy expenditure; NPEE=nonprotein energy expenditure.

Total Energy Expenditure by Doubly-Labeled Water Method

Free-living energy expenditure (TEE) averaged 2434 ± 520 kcal/d or 48 ± 10 kcal·kg⁻¹·d⁻¹ in the low BMI group, 2452 ± 404 kcal/d or 40 ± 6 kcal·kg⁻¹·d⁻¹ in the normal BMI group, and 2805 ± 557 kcal/d or 35 ± 6 kcal·kg⁻¹·d⁻¹ in the high BMI group. TEE, plus the estimated energy deposited in tissues, will be used to estimate dietary energy needs of pregnant women.

The mean physical activity levels (PAL=TEE/BMR) of 2.06 ± 0.39 , 1.85 ± 0.27 , and 1.86 ± 0.39 for the low, normal and high BMI groups, respectively, would be classified as heavy (1.82),

according to FAO/WHO/UNU (4); however, there is considerable individual variation. The PAL values at 22 and 36 wk of pregnancy indicate a definite trend for physical activity to decrease progressively with advancing gestation in all three BMI groups.

Measurements of TEE, AEE, and PAL will allow us to assess changes in activity during pregnancy and the postpartum period. In conjunction with the fitness and strength tests, we can assess whether pregnancy-induced changes in activity influence the ability to return to military duty.

Table 15. Total energy expenditure (TEE) by doubly-labeled water method				
Low BMI Group	Pre-pregnancy n=16	22 wk pregnancy n=7	36 wk pregnancy n=6	24 wk postpartum n=5
^2H dilution space (kg)	30.28 \pm 3.17*	32.33 \pm 2.72	35.87 \pm 4.10	28.24 \pm 3.37
^{18}O dilution space (kg)	29.25 \pm 3.17	31.33 \pm 2.43	34.84 \pm 3.69	27.32 \pm 3.19
$^2\text{H}/^{18}\text{O}$	1.04 \pm 0.02	1.03 \pm 0.02	1.03 \pm 0.02	1.03 \pm 0.03
RCO_2	19.09 \pm 4.08	19.97 \pm 2.33	20.57 \pm 4.86	16.61 \pm 3.83
RO_2	22.20 \pm 4.75	23.23 \pm 2.71	23.92 \pm 5.65	19.31 \pm 4.46
EE (kcal/d)	2434 \pm 520	2546 \pm 297	2622 \pm 620	2117 \pm 489
EE (kcal/kg/d)	48.23 \pm 9.66	45.96 \pm 5.17	43.13 \pm 11.23	42.30 \pm 12.10
TEE/BMR	2.06 \pm 0.39	1.92 \pm 0.26	1.80 \pm 0.44	1.79 \pm 0.50
Normal BMI Group	Pre-pregnancy n=37	22 wk pregnancy n=20	36 wk pregnancy n=17	24 wk postpartum n=9
^2H dilution space (kg)	33.30 \pm 3.72	35.07 \pm 4.35	40.90 \pm 4.15	33.45 \pm 4.90
^{18}O dilution space (kg)	32.01 \pm 3.58	33.72 \pm 4.18	39.33 \pm 3.99	32.16 \pm 4.71
$^2\text{H}/^{18}\text{O}$	1.04 \pm 0.02	1.03 \pm 0.02	1.02 \pm 0.04	1.02 \pm 0.03
RCO_2	19.24 \pm 3.17	18.85 \pm 2.80	21.23 \pm 2.60	20.10 \pm 3.38
RO_2	22.37 \pm 3.68	21.92 \pm 3.26	24.69 \pm 3.02	23.38 \pm 3.93
EE (kcal/d)	2452 \pm 404	2403 \pm 357	2706 \pm 331	2563 \pm 431
EE (kcal/kg/d)	40.38 \pm 5.78	37.44 \pm 5.59	37.22 \pm 4.85	41.89 \pm 5.56
TEE/BMR	1.85 \pm 0.27	1.69 \pm 0.28	1.59 \pm 0.25	1.94 \pm 0.22
High BMI Group	Pre-pregnancy n=14	22 wk pregnancy n=4	36 wk pregnancy n=3	24 wk postpartum n=2
^2H dilution space (kg)	37.27 \pm 5.50	38.67 \pm 2.54	42.76 \pm 1.95	36.44 \pm 3.63
^{18}O dilution space (kg)	46.22 \pm 4.96	48.06 \pm 5.83	48.96 \pm 6.02	48.97 \pm 3.88
$^2\text{H}/^{18}\text{O}$	1.03 \pm 0.02	1.03 \pm 0.01	1.03 \pm 0.01	1.02 \pm 0.03
RCO_2	22.01 \pm 4.37	21.33 \pm 4.72	21.33 \pm 7.09	19.55 \pm 3.34
RO_2	25.59 \pm 5.08	24.80 \pm 5.49	24.80 \pm 8.25	22.73 \pm 3.89
EE (kcal/d)	2805 \pm 557	2719 \pm 602	2719 \pm 904	2492 \pm 426
EE (kcal/kg/d)	34.94 \pm 6.47	33.48 \pm 5.81	30.54 \pm 7.25	33.27 \pm 0.25
TEE/BMR	1.86 \pm 0.39	1.76 \pm 0.17	1.57 \pm 0.37	1.80 \pm 0.16

*Mean \pm SD

Fitness and Strength

The measurement of VO_2max allowed us to categorize these women in terms of pre-pregnancy fitness. The mean VO_2max of $38 \text{ ml/kg}^{-1}\text{min}^{-1}$ for the low BMI group, and $34 \text{ ml/kg}^{-1}\text{min}^{-1}$ for the normal BMI group would be in the "average" range of fitness, defined as $34\text{-}38 \text{ ml/kg}^{-1}\text{min}^{-1}$ for women. The mean VO_2max for the high BMI group of $26 \text{ ml/kg}^{-1}\text{min}^{-1}$ would be categorized in the "low" range of fitness. There was considerable variability in the level of fitness in all BMI groups. The maximal heart rates and the high RQ (1.2) also demonstrate that a true maximum was achieved. The maximal workload averaged 157, 171, and 157 watts, in the 3 respective groups, indicating a fairly high level of work reached at exhaustion.

For the one-repetition maximum strength testing, it appears that these women are fairly strong prior to pregnancy. The women can bench press about 65, 59, and 48% of their body weight, in the 3 respective groups. For the lower body, the leg extension measurement indicates a high degree of strength (80, 90, 98 lbs). As with the fitness levels, there seems to be a great deal of variability in the group for strength. About half the women report that they strength train regularly.

Changes at 6 and 24 wk postpartum from pre-pregnancy measurements were examined in a subset of women ($N=14$). $\text{VO}_2\text{max/kg}$ was lower 6 wk postpartum ($27, 29, 21 \text{ ml/kg}^{-1}\text{min}^{-1}$) and almost recovered to pre-pregnancy baseline at 24 wk postpartum ($39, 31, 24 \text{ ml/kg}^{-1}\text{min}^{-1}$), in the 3 respective BMI groups. Strength measures also decreased slightly for the leg press (53, 62, 20 lbs) and leg extension (70, 84, 90 lbs), and more markedly for the bench press (71, 76, 75 lbs), with little change in the latissimus pulldown. Although the sample size is small at this point, it is interesting to note these decreases in fitness and strength at 6 wk postpartum. As more of the women complete all the fitness and strength tests, we will be able to assess whether women in the military can accomplish their work tasks when they are asked to return to duty after pregnancy.

Table 16. Physical fitness and strength

Low BMI Group		Pre-pregnancy n=18	6 wk postpartum n=7	24 wk postpartum n=5
Steady state exercise on stationary cycle ergometer				
Workload	watts	50 ± 0*	50 ± 0	50 ± 0
Heart rate	bpm	120 ± 19	129 ± 23	132 ± 25
VO ₂	lpm	0.87 ± 0.08	0.84 ± 0.04	0.88 ± 0.09
VO ₂ /kg	ml/kg/m	17.16 ± 1.99	16.12 ± 1.28	17.42 ± 3.26
RQ		0.92 ± 0.07	1.03 ± 0.09	1.02 ± 0.10
Maximal exercise on stationary cycle ergometer				
Workload	watts	157 ± 41	123 ± 23	151 ± 56
Heart rate	bpm	177 ± 9	174 ± 13	182 ± 5
VO ₂	lpm	1.94 ± 0.47	1.45 ± 0.19	1.85 ± 0.63
VO ₂ /kg	ml/kg/m	38.31 ± 9.11	27.74 ± 3.11	36.21 ± 10.83
RQ		1.21 ± 0.07	1.24 ± 0.09	1.25 ± 0.09
Strength testing: 1-repetition maximum				
Leg press	lb	82 ± 41	72 ± 29	66 ± 38
Leg extension	lb	80 ± 18	70 ± 9	84 ± 19
Bench press	lb	72 ± 56	80 ± 59	79 ± 53
Latissimus pull-down	lb	63 ± 13	54 ± 10	56 ± 5
Submaximal exercise on treadmill @ 2.5 mph				
Heart rate	bpm	95 ± 13	112 ± 11	103 ± 7
VO ₂	lpm	0.60 ± 0.08	0.66 ± 0.06	0.60 ± 0.06
RQ		0.89 ± 0.03	0.88 ± 0.03	0.90 ± 0.04
Energy expenditure	kcal/m	2.95 ± 0.38	3.25 ± 0.26	2.97 ± 0.29
Normal BMI Group		Pre-pregnancy n=40	6 wk postpartum n=15	24 wk postpartum n=11
Steady state exercise on stationary cycle ergometer				
Workload	watts	50 ± 0	50 ± 0	50 ± 0
Heart rate	bpm	120 ± 17	119 ± 20	109 ± 23
VO ₂	lpm	0.91 ± 0.05	0.90 ± 0.08	0.91 ± 0.09
VO ₂ /kg	ml/kg/m	15.23 ± 1.59	14.08 ± 2.35	15.08 ± 1.65
RQ		0.93 ± 0.06	1.01 ± 0.09	0.99 ± 0.08
Maximal exercise on stationary cycle ergometer				
Workload	watts	171 ± 34	147 ± 38	158 ± 45
Heart rate	bpm	178 ± 9	172 ± 10	170 ± 13
VO ₂	lpm	2.07 ± 0.41	1.79 ± 0.36	1.88 ± 0.43
VO ₂ /kg	ml/kg/m	34.34 ± 6.29	27.70 ± 5.63	30.83 ± 6.28
RQ		1.22 ± 0.08	1.31 ± 0.10	1.27 ± 0.12

Table 16. Physical fitness and strength (cont)

Strength testing: 1-repetition maximum				
Leg press	lb	81 ± 30	68 ± 24	83 ± 35
Leg extension	lb	90 ± 22	89 ± 27	96 ± 28
Bench press	lb	78 ± 50	76 ± 52	78 ± 56
Latissimus pull-down	lb	65 ± 11	61 ± 13	65 ± 11
Submaximal exercise on treadmill @ 2.5 mph				
Heart rate	bpm	95 ± 13	106 ± 14	90 ± 14
VO ₂	lpm	0.68 ± 0.11	0.77 ± 0.12	0.64 ± 0.10
RQ		0.90 ± 0.03	0.89 ± 0.04	0.90 ± 0.03
Energy expenditure	kcal/m	3.35 ± 0.54	3.80 ± 0.61	3.18 ± 0.51
High BMI Group				
		Pre-pregnancy n=20	6 wk postpartum n=3	24 wk postpartum n=2
Steady state exercise on stationary cycle ergometer				
Workload	watts	50 ± 0	50 ± 0	50 ± 0
Heart rate	bpm	122 ± 17	128 ± 11	149 ± 6
VO ₂	lpm	1.04 ± 0.07	0.97 ± 0.02	1.23 ± 0.19
VO ₂ /kg	ml/kg/m	12.83 ± 1.51	11.73 ± 0.65	14.83 ± 2.04
RQ		0.96 ± 0.05	1.05 ± 0.07	1.06 ± 0.04
Maximal exercise on stationary cycle ergometer				
Workload	watts	157 ± 25	138 ± 23	130 ± 7
Heart rate	bpm	181 ± 13	172 ± 8	181 ± 8
VO ₂	lpm	2.10 ± 0.28	1.86 ± 0.26	1.84 ± 0.19
VO ₂ /kg	ml/kg/m	25.87 ± 3.75	22.42 ± 2.35	22.22 ± 1.91
RQ		1.20 ± 0.06	1.25 ± 0.16	1.23 ± 0.01
Strength testing: 1-repetition maximum				
Leg press	lb	65 ± 39	50 ± 36	80 ± 46
Leg extension	lb	98 ± 21	98 ± 29	123 ± 25
Bench press	lb	86 ± 55	86 ± 63	102 ± 66
Latissimus pull-down	lb	69 ± 11	63 ± 5	70 ± 10
Submaximal exercise on treadmill @ 2.5 mph				
Heart rate	bpm	106 ± 9	123 ± 7	119 ± 3
VO ₂	lpm	0.90 ± 0.15	0.93 ± 0.19	0.89 ± 0.13
RQ		0.91 ± 0.03	0.90 ± 0.01	0.93 ± 0.00
Energy expenditure	kcal/m	4.44 ± 0.74	4.62 ± 0.95	4.41 ± 0.66

*Mean ± SD

8. CONCLUSIONS

This study addresses the impact of pregnancy-induced changes in body composition and physical fitness on postpartum return to duty readiness. In this third annual report, preliminary data are presented on the subjects enrolled thus far. Prior to conception, the subjects represent healthy, moderately-active women. Based on military standards, nearly all subjects in the low and normal BMI groups would be eligible for the Armed Services. The weight, body fat, bone

density and iron status of these women are within normal limits. Energy expenditure measurements indicate that these women are physically active. VO_2max and strength tests confirm that the women are fit and fairly strong. Our evaluation of military equations for the prediction of fat mass based on 82 women prior to pregnancy strongly indicates a need to revise the equations. The Army and Navy equations underestimate body fat. Although conservative, the equations do not perform equally across the range of body fat mass. The underestimation is exaggerated at higher levels of fat mass. Our preliminary data indicate a mean gestational weight gain of 15.6 kg and deconditioning at 6 wk postpartum. Further, the effect of gestational weight gain, fat accretion and deconditioning on the ability to return to weight, body fat and fitness standards in the 6 mo following delivery will be assessed. With more complete data we will be able to test our hypothesis that moderate levels of physical activity will maintain physical fitness and limit excess fat deposition during pregnancy and facilitate fat mobilization and conserve fat-free mass during postpartum weight loss.

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